Addendum to the P-907 proposal

October 2001

P907 Collaboration

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Abstract

We describe the progress made over the last year towards making the experiment a reality. Progress has been made on all fronts including preparing the experimental hall, fixing magnet coils, and bringing up various detector components, such as the time projection chamber (TPC), the Ring Imaging Cerenkov (RICH) and wire chambers. We have a fully functional Monte Carlo that has been used to optimize the detector placements and also to design a time of flight (TOF) system. We estimate the cost of installing the experiment and propose a funding scenario. We describe an installation and running plan that fits in with the current long range schedule of the laboratory. We justify the nuclear physics/heavy ion physics case of P-907, as requested by the PAC.

Contents

1 Introduction

After P-907[1] was deferred by the PAC in November 2000, the Fermilab directorate encouraged us to conduct an R&D phase of the experiment to demonstrate that the collaboration can function together to make the experiment viable. We have in the ensuing time divided our activities into the following categories.

- **TPC Cosmic Ray test.** A clean room was constructed in Meson Test area to house the TPC. The TPC has been connected to the water chiller and wired up to take data. The gas system for the TPC is being hooked up and preparations are being made for a cosmic ray test in October.
- **Refurbish wire chambers.** The E690 wire chambers have been taken out of storage. All chambers hold high voltage in air. They are being prepared currently to flow gas and test with a source.
- **Write a new Data Acquisition System.** With the help of Fermilab Computing division personnel, a linux based data acquisition system is being written for the experiment. This will be used in the TPC cosmic ray tests.
- **Refurbish the RICH.** The phototubes and electronics of the Selex RICH have been tested. The RUSSIAN made hybrid chips in the RICH front-end electronics will have to be replaced.
- **Write a Geant based Monte Carlo.** A fully functional Geant based Monte Carlo has been written for the experiment and is being used to optimize the design.
- **Design a Time of Flight system.** Using the Monte Carlo, we have designed a time of flight system to enhance the particle identification capabilities of the experiment in the momentum region 0.7 GeV/c to 2.5 GeV/c.
- **Design the Beam to the experiment.** The Switchyard 120 project now includes the beam to experiment 907. The beam is being redesigned to take into account the geometry changes (in beam height) to the experiment introduced as a result of the support structures,

- **Fix the Jolly Green Giant coil.** One of the four coils of the Jolly Green Giant magnet has had a short in it for sevral years. Using money obtained as a result of a Livermore ICO, we have fixed the coil using the services of a California company.

- **Clean out the Experimental Hall.** The Meson Center Experimental Hall (MC7) which used to house the HYPER-CP experiment has been cleaned out, again using the ICO money.

- **Engineer and install the magnet support structure in Meson Bottom.** We have engineered the support structure needed to bear the combined weights of the Jolly Green Giant and ROSY magnets. The hall beneath MC7 (M-Bottom) has beein re-inforced with a steel structure and the floor of MC7 has been re-inforced with a 1 ft concrete slab to support the weight of the magnets evenly. We have used ICO money for this. The total amount of ICO money spent to date on 907 activities totals $228,000.

P907 was also encouraged to further develop the case for nuclear/heavy-ion physics, to develop specific running scenarios, to develop a detailed cost and schedule plan, and to identify funding sources outside Fermilab. These issues are addressed in the following sections.

2 Physics Case Update

2.1 Medium Energy Nuclear Physics

Medium Energy Physics came into existence roughly four decades ago at the cusp between nuclear and high-energy physics. While its scope is quite broad, one of the primary motivations in precipitating out this distinct field was the quest to understand the physics of the nucleus through a more precise understanding of the nature of the interactions of the constituents of the nucleus. While it is not our purpose here to review the accomplishments of this field, suffice it to say that the problem has turned out to be considerably more intractable than was thought in the early days of constructing the meson factories. The quark structure of matter and QCD were only dawning ideas at the time, and these have lead us on many unanticipated paths. The program we are proposing here has, we believe, a common heritage with the philosophical underpinnings of Medium Energy Physics. While the study of relativistic heavy-ion physics has motivating factors that go beyond just understanding the nature of the "normal" nucleus, it still includes the link to the original thread of probing the underlying behavior of nuclear matter. Our quest is to pursue the more complete understandings of the interactions of the constituents of the nucleus with nuclear matter (such as in p-p, π-A and p-A) that are needed to approach the complex problems posed when trying to describe relativistic nucleus-nucleus collisions.

It is reasonable to ask why, after so many decades of experiments in these simpler systems, we still need more data. The answer is that in order to accurately model what occurs, one needs to know the inclusive cross sub-subsections for nucleons and mesons in nuclear matter. Virtually all of the existing data are exclusive. The reason for this is obvious. Measuring an inclusive cross subsubsection is a very difficult task. In fact, the best that can reasonably be done is to approach that with semi-inclusive measurements that still generally lack the unambiguous identification of all of the neutral products. Exclusive measurements have been made to great precision in quite a number of channels, but a quick look at the resonance tables from the Particle Data Group still reveals significant uncertainties. However, the greater issue is that it is not possible in complex situations to assemble the full inclusive cross-subsubsection data, even from exhaustive exclusive data. This is perhaps best illustrated by referring to the well-known problems in the Nuclear Physics neutron transport codes that accurately reproduce the exclusive channel data with high statistics, but have problems conserving energy and momentum for individual events, let alone getting the final-state particle correlations right. This is borne out most strikingly at present in the attempts to look for evidence of neutrino oscillations. To understand the expected atmospheric neutrino production characteristics, or even the nature of the beam for long baseline experiments, substantially more data are needed. The goal is to amass sufficient statistics to attack the problem of understanding A-A collisions, and along the way perhaps to gain a finer understanding of the nature of nuclear matter and its constituents. E907 will produce high statistics data with full particle identification in the final state of hitherto unmatched which will facilitate modeling of shower Monte Carlos.

2.2 Heavy Ion Physics

By measuring Λ, Ξ, and Ω production in proton-nucleus collisions as function of the average number of inelastic collisions of the incident proton FNAL E907 will be able to address a recent measurement of enhanced strange and multi-strange baryon production in 158 A·GeV/c Pb+Pb collisions at the SPS. These data will improve understanding of the mechanisms for strangeness production in nuclear (and hadronic) collisions and will test recent predictions of a phenomenological model for the baryon structure known as the junction [11, 10]. Finally, future comparisons of results from the proton-nucleus program at RHIC to data from E907 will play a vital role understanding phenomena that are unique to heavy-ion collisions at RHIC energies.

Discovering and studying the QCD phase transition has been the goal of the relativistic heavy-in programs at the BNL AGS, CERN SPS, and now RHIC. Such a discovery depends on the experiments' ability to extract a set of final state signatures which would mark the occurrence of a the phase transition. Proton-nucleus collisions play a crucial role in providing a calibration for the predicted signatures, both through direct comparison to nucleus-nucleus data, and as input to phenomenological models for nucleus-nucleus collisions.

By the time RHIC was to be commissioned, the CERN program had produced a set of results that were inconclusive when taken individually, but were intriguing when considered together. In the spring of 1999, CERN issued a press release stating that a new state of matter had been formed in heavy-ion collisions. However, there were and still are significant gaps in comparable pA results for many of the proposed signatures. Two of the more important measurements which constitute evidence for new matter formation in Pb+Pb collisions at CERN are the enhanced yields of strange baryons in CERN-WA97 and the suppression of J/ψ charmonium in NA50. The latter result depends on a parameterization of the nuclear absorption/formation of J/ψ in proton-nucleus collisions, and FNAL E866 and successor P906 are providing important data for understanding the nucleus-nucleus results.

The WA97 results [4] in Fig. 1 show enhanced yields at mid-rapidity of strange and multi-strange baryons per participant nucleon (N_{wound}). Total charged particle yields at mid-rapidity have been observed to be approximately linear in the number of participants or wounded nucleons [5]. The use of this scaling has its origins in the seminal results of an early proton-nucleus

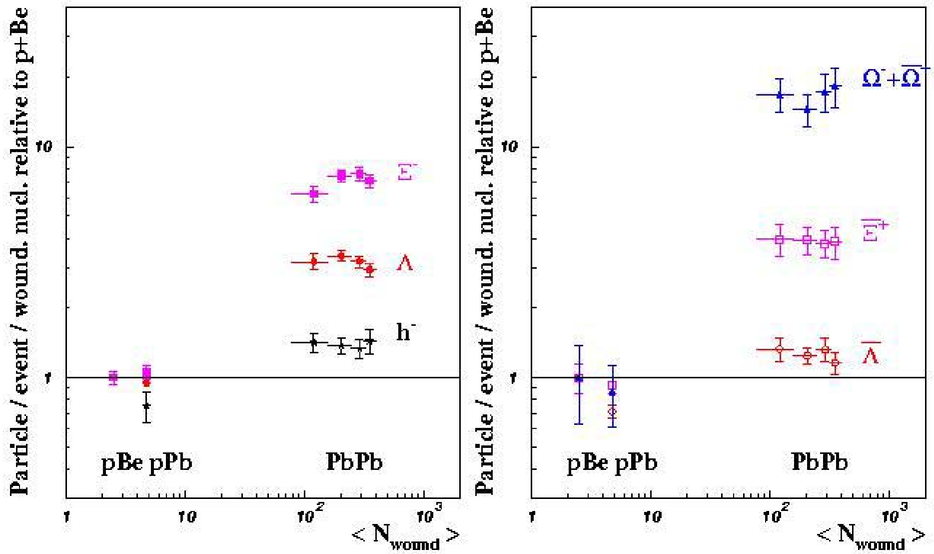

Figure 1: Hyperon yields per wounded-nucleon in WA97.

experiment run at FNAL [6] which demonstrated that the total charge particle multiplicities are proportional to ν, the mean nuclear thickness traversed by the projectile in a hadron-nucleus collision. For pA collisions, $N_{wound} = \nu + 1$.

However, enhanced strangeness per wounded nucleon is only a meaningful signature of new physics if it can be shown that a similar enhancement is absent in proton-nucleus collisions. The two data points in Fig. 1 for p+Be and p+Pb are insufficient to make this claim.

The total Λ production in pA collisions has recently been measured by BNL E910 in 18 A·GeV/cp+Au collisions [7]. Fig. 2 shows Λ yields per event measured vs. the quantity ν or ($N_{wound} - 1$), measured within the acceptance and extrapolated outside the acceptance. The solid line is the expected wounded nucleon scaling, and the dashed line is the scaling based on the number of collisions. Fig. 2 shows unambiguously that Λ production is enhanced relative to the wounded nucleon scaling. In fact, production initially follows an $N_{collision}$ scaling before saturating after $\sim$3 collisions.

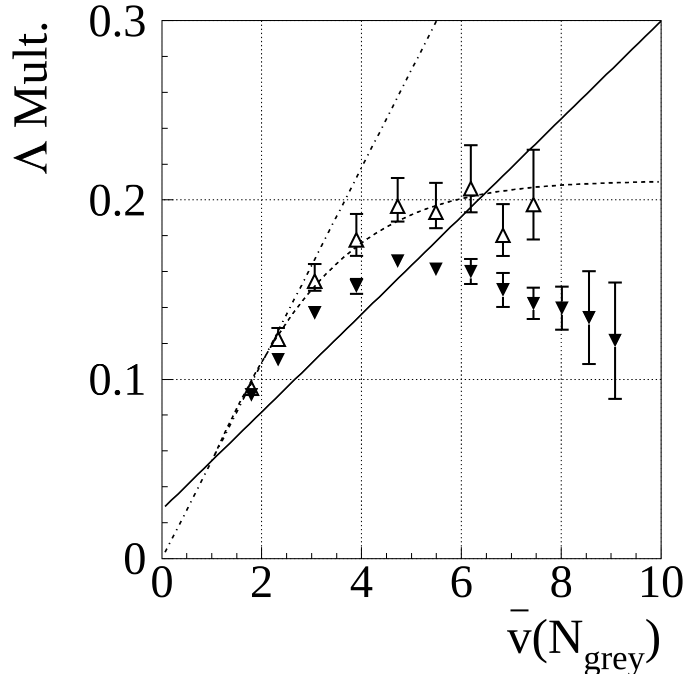

Figure 2: E910 Lambda yields vs. ν for 18 GeV/c p+Au collisions.

It is possible to extrapolate this enhancement in proton-nucleus collisions to heavy-ion collisions by using a parameterization of the pA enhancement as input in a glauber model for heavy-ion collisions. Fig 3 shows the results for such an extrapolation from E910. For the E910 calculation the energy difference is accounted for by a single multiplicative factor which corresponds the the energy dependence measured in pp collisions. Similar results for Λ and Ξ production in 200 GeV/c p+Pb collisions have been reported by NA49 (Fig. 4. In both cases, the remaining enhancement is significantly reduced. Details of these comparisons are discussed in the manuscripts that are in preparation by each collaboration.

One reason that this result has not been measured earlier is that E910 is the first experiment to combine a high statistics strange particle data set with a simultaneous measure of ν, extracted from the number of target recoil nucleons in the TPC [8]. Using the TPC E910 has been able to identify the

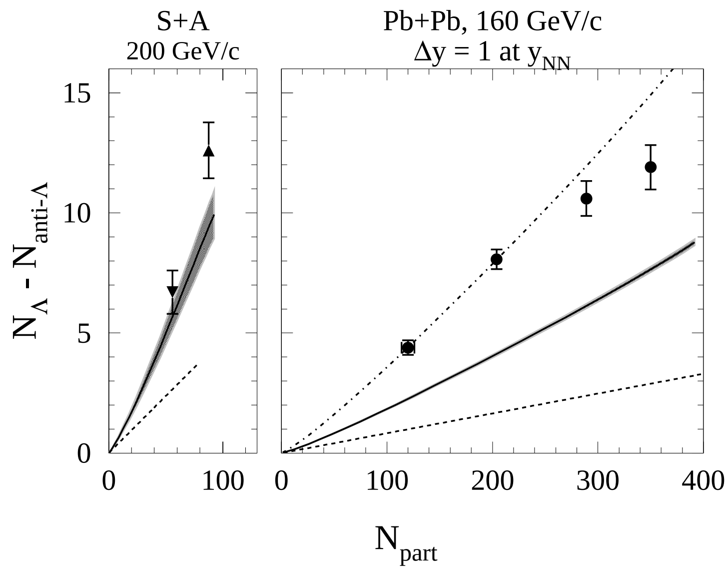

Figure 3: Extrapolations of E910 proton-nucleus strangeness enhancement to heavy-ion results form WA97. N_{wound} scaling, dashed; E910 extrapolation, solid; Extrapolation with acceptance correction, dot-dashed.

top 1% most central events. The NA49 measurement confirms the implications for WA97 but the detector used to measure recoil nucleons had a more limited acceptance for this task; the centrality resolution was less precise. E907 will combine the high energy data set with the large acceptance for recoil nucleons provided by the TPC. In addition, the expected data sets should yield a measure of Ω vs. N_{wound}.

It has long been thought that the dominant mechanism for exciting and fragmenting the proton in hadronic interactions is the dissociation of one of the valence quarks from the proton through color exchanges with the interacting hadron. Processes that break the diquark or remove all three valence quark from the incoming proton might significantly increase the likelihood of producing singly and multi-strange baryons. In fact, Van Hove [9] in his

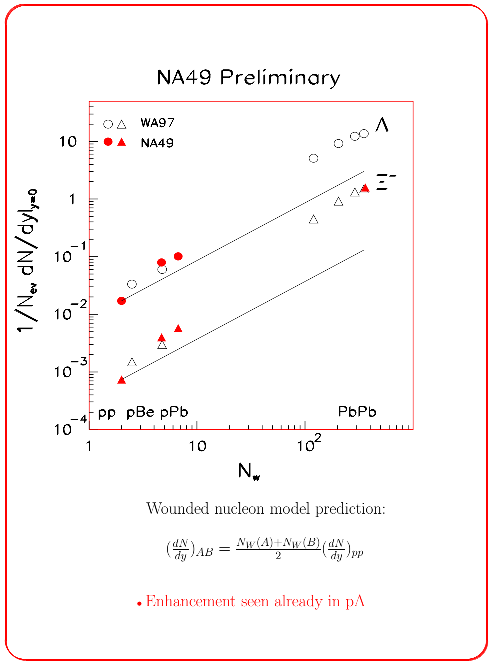

Figure 4: Comparison of results from NA49 and WA97 reported at Quark Matter 2001 Conference.

early model of baryon fragmentation directly related Ξ and Ω production rates to the probability of stripping 2 and 3 quarks from the baryon in a high-energy collision. An increase in multi-strange baryon production from multiple valence quark stripping processes results simply from the fact that as more valence quarks are stripped, the probability for picking up a strange quark from the sea increases. Considerations of such processes have been spurred by the resurrection of the "baryon junction" originally proposed by Veneziano [11]. The removal of the three valence quarks from a baryon leaves the junction behind and, in the process of becoming color neutral, the associated gluons must pick up replacement quarks out of the sea. Attempts have been made to constrain the parameters of the junction in Regge theory using $p\bar{p}$ annihilation data. Removing the three quarks from the incident proton, processes involving excitation of the junction, may lead to increased strange and multi-strange baryon production [10]. In particular, it will lead to events in which an Omega is produced in association with 3 kaons. While the extraction of the junction may be difficult in interactions in which it is rare (*pp* collisions), it might be much more likely in proton-nucleus interactions in which the baryon undergoes multiple nucleon-nucleon scatterings. Measurements from E907, however, could provide much tighter constraints on such a model. If the junction mechanism does play a role in proton interactions, E907 might be the first to show that clearly by the ability to study both the strange baryon and the associated kaons in events where the proton is known to interact multiple times.

Proton-nucleus (or deuteron-nucleus for machine considerations) running is also an important priority for RHIC. It was the topic of a several workshops at LBNL and BNL, the subject of a white paper submitted to NSAC, and has recently been identified as the highest priority after the existing FY01/02 run plan is completed. It is too early to comment on the significance of the first results from RHIC, but it has become clear that one of the challenges will be to understand the relative components of hard processes, largely absent from the SPS, from the soft process, which appear quite similar to data from the SPS. The multiplicity dependence on centrality is well described by a two component fit, a soft component proportional to N_{wound} and a hard component proportional to $N_{collision}$ [12, 13]. Furthermore, suppression of high p_T hadrons in central collisions, the first qualitatively new result from RHIC, underscores the importance of understanding relative hard and soft contributions. Direct comparisons of proton-nucleus data from E907 and RHIC may play an important role in calculating the relative strengths of these components. An understanding of the energy evolution of proton-nucleus collisions, from the BNL AGS (E910) through the CERN SPS and FNAL E907 to RHIC, is essential to the understanding the corresponding evolution in heavy-ion collisions.

3 Experiment Status

3.1 Time Projection Chamber

E907 will use the EOS TPC, built by LBL circa 1989, as the first tracking detector, and for particle identification of low momentum tracks. The TPC (see Figures 5 and 6) tracks particles in a 75 cm x 96 cm x 150 cm active volume, read out by 15,360 pads, 12 mm x 8 mm in size. Sub-millimeter position accuracy is achieved by charge sharing among adjacent pads. The vertical position accuracy is of order a millimeter, measured by the drift time. The TPC was used successfully by EOS at the Bevelac and by E910 and E895 at the AGS.

Figure 5: Upstream view of the TPC, uncabled. The target bay is clearly seen. The TPC is sensitive to tracks coming from targets placed in the target bay with nearly 4π solid angle acceptance.

We have made substantial progress towards re-commissioning the TPC at FNAL. In this subsubsection we discuss the hardware work; the ata acquisition software is described in the next subsubsection. The hardware work is proceeding in three phases. In August 2000 we performed an initial high voltage test in Industrial Building 4. During the past six months we have been installing the TPC and its infrastructure in the Meson Test area. We are currently preparing for cosmic ray tests. The cosmic ray tests will be complete by the end of 2001, at which time the TPC will be ready to be installed in the experiment in MC7.

The initial high voltage test, in August 2000, demonstrated that the chamber, field cage, and anode wires survived the trip from Brookhaven.

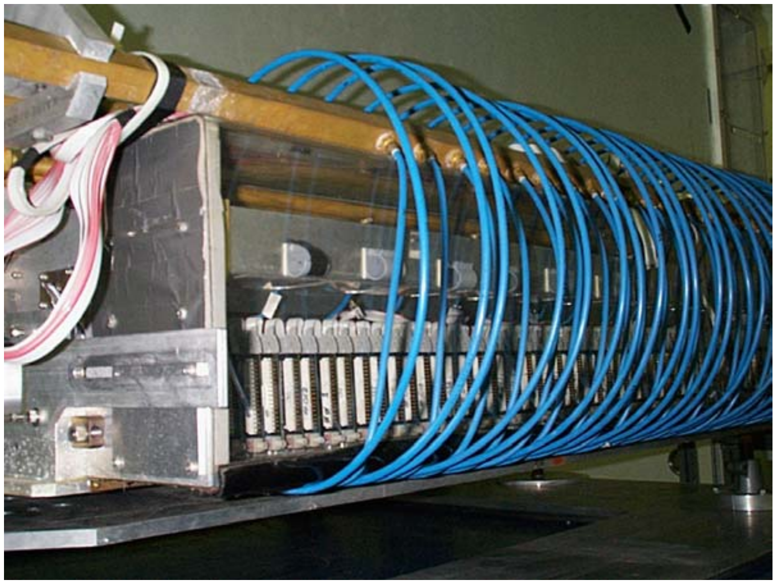

Figure 6: The front-end electronics of the TPC are cooled by chilled water. The data are shipped by optical fibers to VME crates.

In order to protect the field cage from shock loading during transport, the cathode plane was removed for shipment. The initial high voltage test was performed in the CDF clean room of Industrial Building 4, to provide a clean work area during re-installation of the cathode plane. The chamber was flushed with nitrogen, and operating voltage was applied to the cathode plane and the anode wires. The cathode showed purely resistive behavior, with the expected value, 124 MΩ. The anode wires showed high, but acceptable, current. The high current was probably due to water vapor still present in the chamber because of the modest flow rate used during the nitrogen flush. Following this test, the TPC was moved to Lab 7.

In February 2001, we moved the chamber and support equipment to the Test area of the Meson Hall. We built a clean room, (see Fig. 7) with positive pressure, installed the cathode plane, and repeated the cathode plane high voltage test, with similar results.

We have since:

- Installed cooling water distribution lines.

- Refurbished, installed and operated the cooling water system.

Figure 7: The clean room at M-TEST houses the TPC during Cosmic ray tests.

- Installed low voltage power distribution cables.
- Installed master clock and trigger cables and fanout.
- Recommissioned the interlock system with all necessary inputs (air flow, water temperature and flow, clock present).
- Installed the interlock and status repeater.
- Load tested and installed the low voltage power supplies.
- Installed the chamber ground.
- Installed high voltage cables for the cathode and anodes,,
- Installed fiber optic readout cables.
- Installed slow control cables.
- Installed the high voltage power supplies.

As of October 5, we have designed the P10 gas supply system and are currently implementing it. The design calls for a small supply manifold feeding the original gas distribution rack, with a few small modifications. Our flammable gas safety assessment indicates that our installation in MTest will be Risk Class 0, indicating a low hazard risk. The mitigation requirements (signage, venting, purge procedure) are not onerous, and we expect to receive preliminary Operational Readiness Clearance for unattended P10 operation in the month of October.

We are simultaneously pursuing clearance for high voltage operation with P10, which will enable the cosmic ray tests. Initially, we seek clearance for attended high voltage operation, and will eventually obtain clearance for unattended operation.

The only other remaining hardware tasks are to install the gating grid drivers, and resurrect the "canary" chamber, which monitors the drift velocity of the gas. Neither of these is required for the cosmic ray tests. We are also investigating replacing the original fiber optic "spaghetti" (140 separate fibers) with four jacketed fiber optic cables (36 fibers each). These cables are much more robust than the current loose fibers and would supply an adequate number of spares.

Our cosmic ray tests will occur largely in November and December. We plan to address a number of issues. We have 134 of the custom front end "Sticks;" the TPC needs 128. We also have 38 of the custom VME "Receiver" cards; the TPC needs 32. For both the sticks and the reciever cards, we do not know which are operating and which need repair. The first goal of the testing program is to identify the working, spare and broken cards. (The cards use two custom chip designs. We have several dozen of each packaged and tested, and many more in wafer form. All other key components are still available commercially.)

The second goal of the test program is to read out cosmic ray muons crossing the chamber, and show that the entire chamber is sensitive (modulo bad sticks). The third goal is to investigate the use of P8 (Ar, 8% CH_4), which is non-flammable, instead of P10 (Ar, 10% CH_4). Finally, reading out cosmic ray muons provides an early development environment for the data acquisition system.

3.2 Data Aquisition System

Substantial progress has been made on the E907 data aquisition (DAQ) system particularly with regard to the TPC readout. The 15,360 pads are arranged in 128 rows, of 120 pads each. Each set of adjacent half rows are readout by a electronics board or "stick". For each pad the 256 time buckets are read out by switched capacter array into a hybrid shaper-amplifier and then digitized. Each stick transmits its data over optical fiber to a custom built receiver card (one per every four sticks) for further signal procesing including pedestal subtraction, zero suppression, and gain correction. The receiver cards are arranged in four front end processor VME crates, each with 8 receiver cards, a processor, 8 MB memory card, interrupt module and bitbus master.

The task of reading out 128 rows x 120 pads x 256 timebuckets x 2 bytes ADC is formidable, and even after zero-suppression the TPC dominates any data stream to be taken by E907 (70% of a ~100 kbyte event size). Therefore the overall data aquisition is designed around the need to accomodate the TPC. In all past experiments using the TPC, the data from the receive cards were processed by two event builder processors, buffered in memory and then written to 8 mm tape. Past performance of the DAQ was adequate, but never achieved the maximum 60 Hz rate set by the 16 ms SCA readout [2]. Insufficient memory buffering in the event builder crates is the most likely bottleneck.

For the E907 DAQ, we will continue to use the custom built stick and receiver cards, but the event builder will be significantly upgraded. The layout of the new DAQ is given by Fig. 8. The lower right subsubsection of Fig. 8 shows the four front end VME crates, largely unchanged from earlier configurations of the TPC. The upper right subsubsection includes CAMAC readout of all other detector systems. The central portion shows the E907 event builder, which relies heavily on software tools supplied by the Fermilab Computing Division, and especially members of Online Data for Experiments: Margaret Votava, Dave Slimmer, Luciano Piccoli, and David Berg. In the current design, the TPC front end crates write data to the event builder memory buffer over VSB, and CAMAC creates are read out via the CES8210. We intend to use Luciano's event builder package, R2DM, to construct the events and send them to a dual-processor linux workstation (e907daq) over ethernet. The data stream will then be archived using ENSTORE. Error logging will be done using the MERLIN package, and an electronic experi-

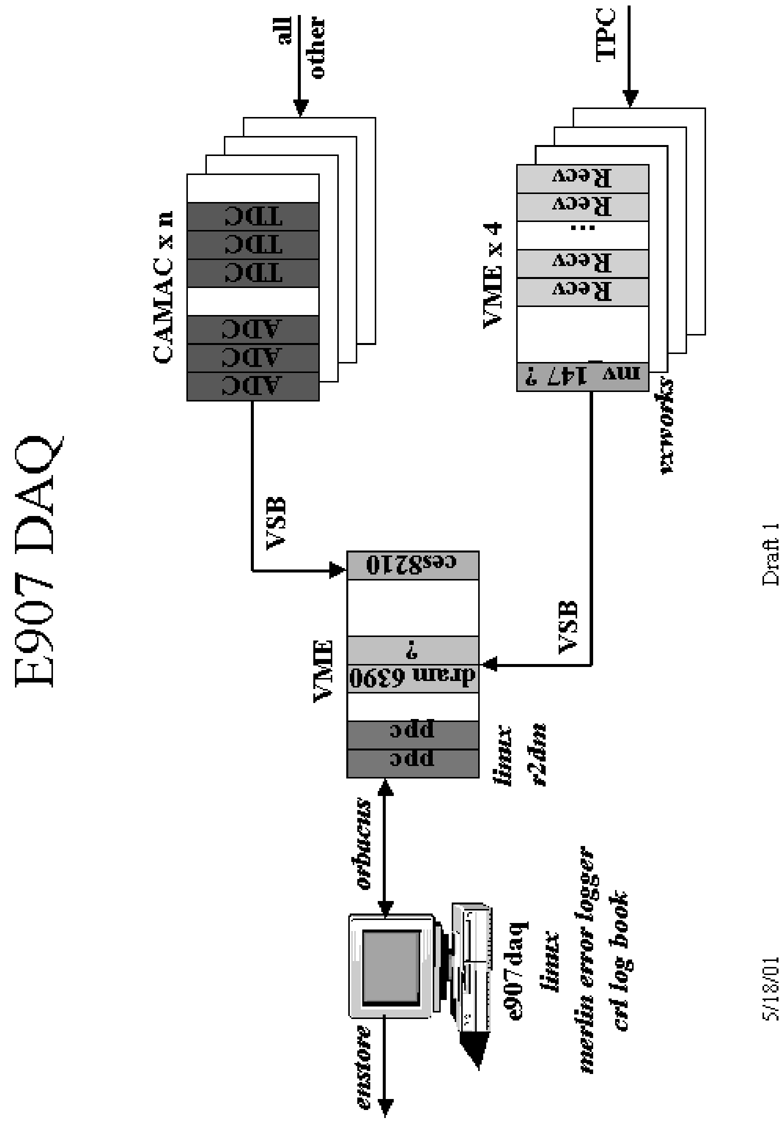

Figure 8: Data Acquisition Layout for E907.

mental logbook will be kept using CRL. Many of these packages have been successfully used by other experiments. In some cases, such as R2DM, E907 is working closely with ODE to further develop existing software.

At the time of writing, the following milestones have been achieved.

- e907daq data aquisition computer configured and fully compliant with FNAL security requirements.
- Bitbus communication to sticks established.
- Readout routines compiled under vxworks and tested on FEP processors.
- DSP receiver code successfully compiled
- R2DM communication tested e907daq and VME processor

The remaining tasks for the TPC readout include booting the receiver card DSP processors, and reading stick data over the optical link into the receiver card memory for event building. Once TPC readout is established, we will develop the top layer of software to readout CAMAC crates using the CES8210 libraries written by Dave Slimmer. The readout of the remaing detectors is greatly simplified by using CAMAC modeles that can be read by the CES8210.

3.3 Wire Chambers

We have removed the E690 wirechambers from their cart in Proton Center and moved them for testing in Lab6. There are 6 chambers each of which is a triplet measuring x,u and v. The High Voltage connectors have been upgraded to comply with current Fermilab standards. The chambers hold voltage under nitrogen indicating that there are no broken wires. A gas system has been designed to flow the “magic gas” mixture of Argon, isobutane, methylal mix. The chamber setup has passed the Saftey review and source and cosmic ray tests are planned in late October. In addition we have put together a cosmic ray telescope test stand for use with both chamber and TPC testing.

Figure 9 Shows a picture of one of the chambers taken while being removed from Proton Center 4.

Figure 9: One of the E690 chambers being refurbished for E907

The precise placement and size of chambers is being currently studied and optimized using the Monte Carlo. We may also decide to use two more large wire chambers available from the SELEX experiment, in addition to the E690 chambers.

3.4 Ring Imaging Cherenkov System

We were able to test the electronics of the RICH during the summer of 2001 with the visit of a Russian engineer who was involved in the initial design of the RICH. We tested all the phototubes and electronics. The following is the summary of the tests.

3.4.1 Photomultiplier Tubes

The LED test and monitoring system was checked and brought into operation. With it, the signals from each of the 2484 photomultiplier tubes (organized in 89 columns each containing 32 tubes) were examined. In the process, 6 columns which drew excess HV current were identified. Figure 10 shows the map of the bad phototubes. For each of these columns, the affected tube and base combination was isolated so that the remainder of the column was made operational. Two tubes were replaced as demonstrations of the necessary techniques.

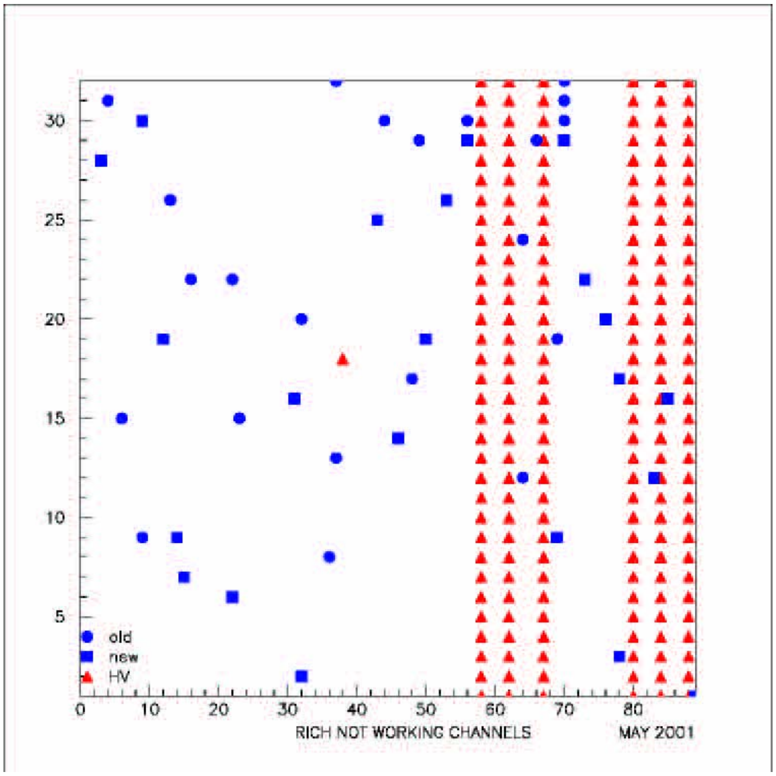

Figure 10: Figure shows the phototubes that are bad. The solid circles show the tubes that were bad at the time of the SELEX experiment, the solid rectangles show the tubes that tested bad during our test. The triangles indicate the six columns of tubes that initally failed to hold HV. These columns were fixed during our test

In the end, only 58 tubes failed to produce acceptable signals. Given its high granularity, the RICH could operate quite successfully with many times this number of dead tubes (as long as they are spread throughout the ring image plane).

3.4.2 Front-end Electronics

The SELEX front-end electronics consists of hybrid chips containing a preamplifier, a discriminator, and an ECL line driver. Each hybrid chip plugs into a socket on a custom card mounted directly on the RICH near the ring image plane – one chip per PMT, 32 chips per card, and one card for each PMT column.

All of the existing front-end electronics units were tested showing that the preponderance of the original Russian-made hybrid chips used on the detector are no longer operational. These failed at a rate of ~1-2% per month during the SELEX experiment, and that rate of failure appears to have continued since the experiment. Only 916 of the ~1800 Russian-made chips in use at the end of SELEX were operational at the time of the test. Some additional hybrid chips were purchased from a US company (Hybrids International, Ltd.) as replacements during the SELEX experiment. Of the 556 tested, only 4 failed. Unfortunately, this company, which had the negatives and masks for the chips, is no longer in business. Additional makeshift replacement boards, based on a Nanometrics N277 discriminator, were also used for SELEX. All 30 of these are in working order, but they can only be used in non-adjacent card slots.

For initial test and commissioning purposes, we could instrument about 75 of the 89 RICH columns at any time. For stable data taking, **at least** 2000 new front-end circuits are needed (if we also use the existing US-made hybrids). It is possible also to redo the electronics based on modern surface-mount technology rather than repeating the hybrid development process. These could be a variant of the RICH electronics which are being built for the CKM experiment. It is estimated that the cost would be in the neighborhood of $15-20 per channel and 5-6 months to build them. For comparison, Hybrids International quoted $25.60 pre hybrid chip (quantity 1000) in 1995.

3.4.3 Readout Electronics

To read RICH data into the E907 DAQ system, one ECL delay and latch channel is required for each front-end discriminator output (2484 total channel). LeCroy PCOSIII modules are available and appropriate for this.

The LeCroy Model 2731A is used in a dedicated CAMAC crate with the Model 2738 in the controller station. In this configuration, the 2731A can be read out at 10x CAMAC speed, 100 nsec per 32-bit word. Data may then be cluster-compacted by the Model 2738. The concentrated data are then transferred through a LeCroy standard DATABUS for readout via a Model 4299 DATABUS Interface in a CAMAC crate with a standard controller. Up to 16 Model 2738 controllers can be connected to a single 4299.

The 2371A is a 32-channel delay and latch, so each module can read out the data from one column of RICH phototubes, and a total of 89 modules are required. Allowing reasonable power margins, an appropriate readout configuration would be as follows (not including spares):

89 LeCroy Model 2371A modules

6 CAMAC Crates

6 LeCroy Model 2738 modules

1 LeCroy Model 4299 module.

These are all available from presently unused PREP electronics inventories at Fermilab.

3.4.4 Gas Selection

Using Neon gas, SELEX achieved a ring radius resolution of 1.7 mm, dictated primarily by the PMT size and the number of PMT hits. For our lower momentum range, a gas with at least 6 times higher refractivity is needed. Since the RICH operates only near atmospheric pressure, this suggests CO_2 as an appropriate gas for our use. It provides a 6.1 times larger photon yield and a 2.5 times increase in ring radius. The larger ring radius will necessitate analysis of partial rings for many particles. Given that we determine the location of each ring center from tracking in the drift chambers, and that we will have more detected photons in the partial rings, this should not pose a problem. Even if we are very conservative and use a poorer 2mm resolution for CO_2, we will have K/pi separation (at 3 standard deviations) up to 80 GeV/c and K/p separation up to 134 GeV/c. While CO_2 does exhibit somewhat higher dispersion than Neon, the estimated contribution of dispersion to the ring resolution remains small. So CO_2 remains the gas of choice.

3.5 Monte Carlo

We have developed a fully functional Geant 3.21 based Monte Carlo to simulate the P-907 detector. It uses a data-driven geometry scheme built with the RCP parameter management system developed for the DØ experiment during Run I. Using this system it is possible to swiftly develop the program since all the constants are contained in structured data files. Figure 11 shows the P-907 set-up as implemented in the Monte Carlo. Superimposed is a 120 GeV/c pp event generated by PYTHIA. In developing the Monte Carlo, we have borrowed code from previous experiments and re-formatted it to our use. We have used the TPC geometry as implemented in BNL experiment E910, the RICH geometry as implemented in the SELEX experiment and the differential Cerenkov geometry as implemented in E690.

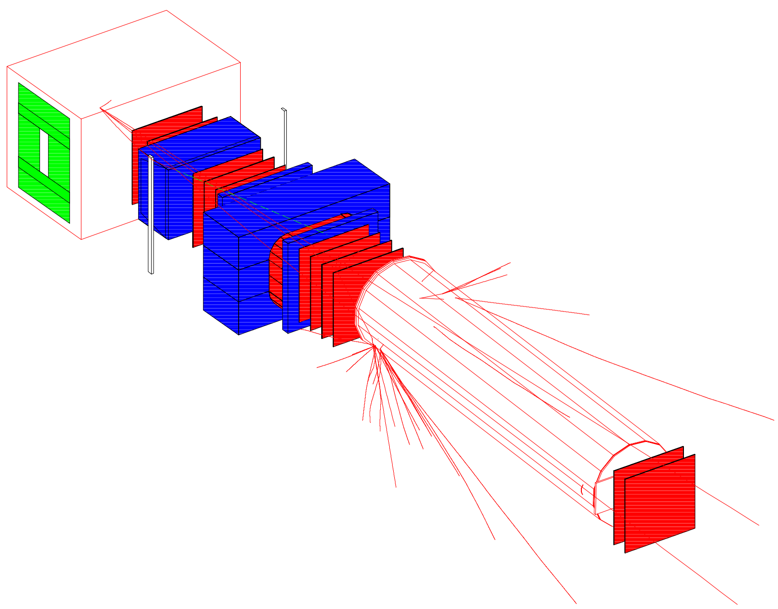

Figure 11: The 907 detector in Monte Carlo. Superimposed is a 120 GeV pp event.

We have used this Monte Carlo to study and optimize various aspects of the P-907 detector. Figure 12 shows the results of a study on the relative polarity and strength of the ROSY magnet vs the Jolly Green Giant magnet. Figure 13 shows the result of a study of momentum resolution of as a function of Rosy polarity.

Figure 14 shows a preliminary analysis of energy deposits in cells using our Monte Carlo. The deposits break into the familiar π, K and p families as a function of momentum. We have also studied the ability of the differential cerenkov to identify particles. Figure 15 shows the median number of photo-

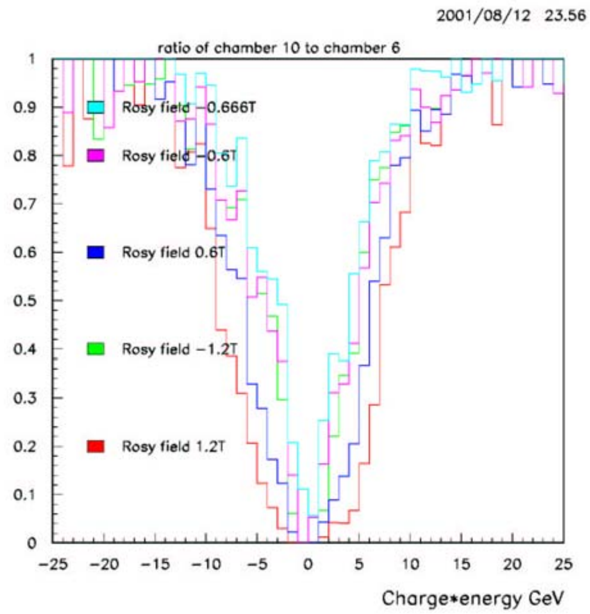

Figure 12: The ratio of particles entering the RICH to those entering the ROSY magnet is plotted as a function of the charge*energy of particles for various ROSY field strengths. Positive ROSY fields bend in the same direction as the Jolly Green Giant. The RICH acceptance is improved for ROSY fields of opposite polarity for particels of energy below 10 GeV.

electrons for an ensemble of tracks as a function of particle momentum. Again a clear separation between $\pi, K and p$ families is seen.

3.6 Time of Flight System

One goal of this experiment is particle ID over the full momentum spectrum. The TPC provides dE/dx measurements for the tracks which allows us to identify the particles up to a momentum about 0.7 GeV/c. The Cherenkov counter will separate pions and kaons for momentum above 2.5 GeV/c, which is the threshold momentum for pions. The Time of Flight (TOF) system will be used to help with particle identification for particles with momentum between 0.7 GeV/c and 2.7 GeV/c.

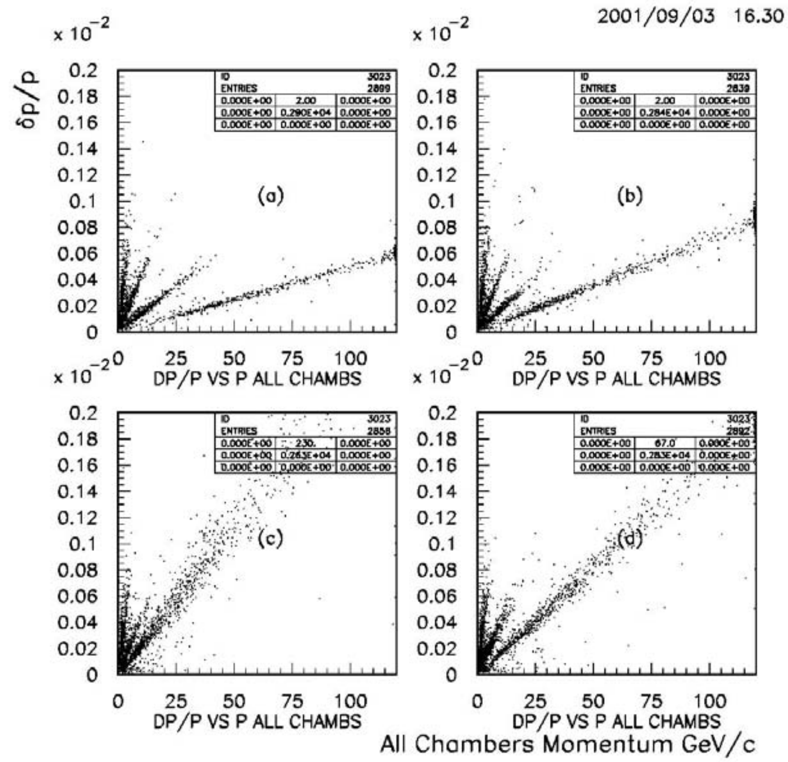

Figure 13: Plot of fractional momentum resolution $\delta p/p$ vs momentum of particle for ROSY fields of (a)+1.2T, (b)+0.6T,(c)-0.6T and (d)-1.2T. The 4 distinct curves are for particle that exit at various points in the detector, the highest momentum particles making it all the way to the end of the RICH, thereby having the lowest fractional momentum resolutions. When the Jolly Green Giant and ROSY oppose each other, this degraded the momentum resolution of the forward going particles as can be seen in (c) and (d).

Our hope was to find a suitable existing TOF detector system from a previous experiment. However, we have been unable to locate a complete system which is adequate for our purposes. Since a complete system is not available, we plan to use existing scintillator available at Fermilab to put together a system with about 200ps resolution from recycled parts. At this

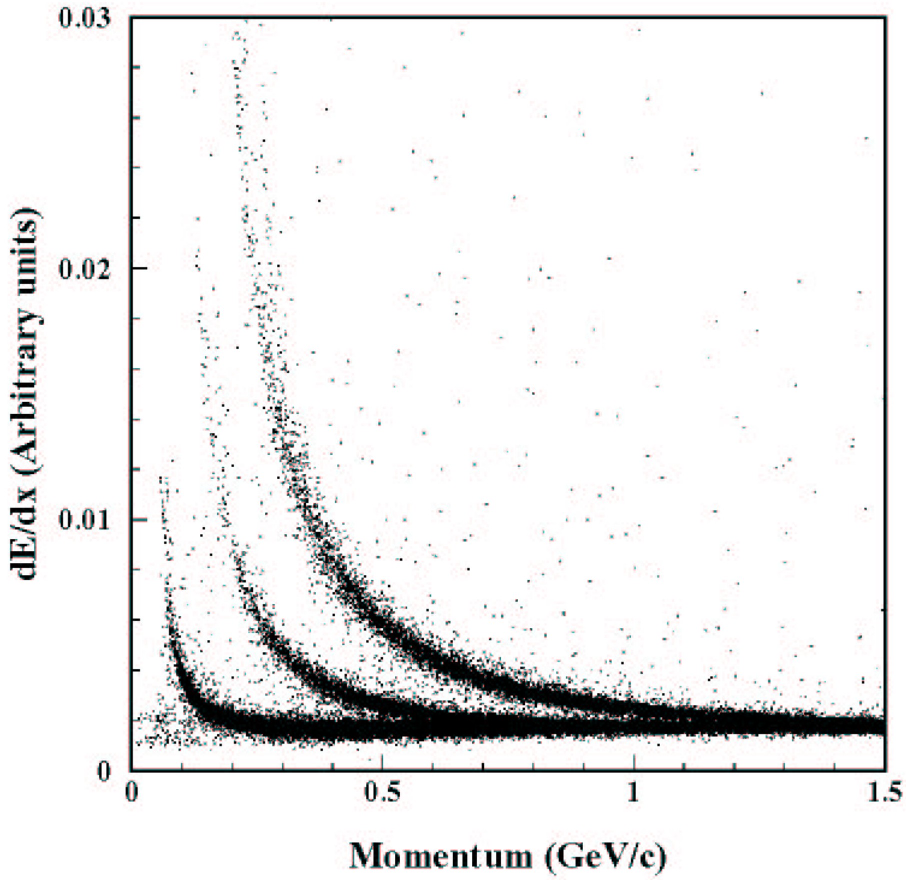

Figure 14: Figure shows a preliminary analysis of dE/dx in the TPC using our Monte Carlo. Deposits consistent with pions, kaons and protons can be seen.

resolution we will be able to cover the crossover region in the π/K separation from the TPC dE/dx measurements. We are in the process of evaluating the stock of scintillator, phototubes, and bases available at Fermilab.

When one examines the physics of the NUMI/MINOS experiment and to a lesser extent atmospheric neutrino measurements which lack the focusing magnets, a majority of the neutrinos of interest are produced from positive particles. Thus when one tries to understand the neutrino spectra observed at these experiments, it is more important to have a measurement of the π/K separation for the positive species than for the negative. To further aid these

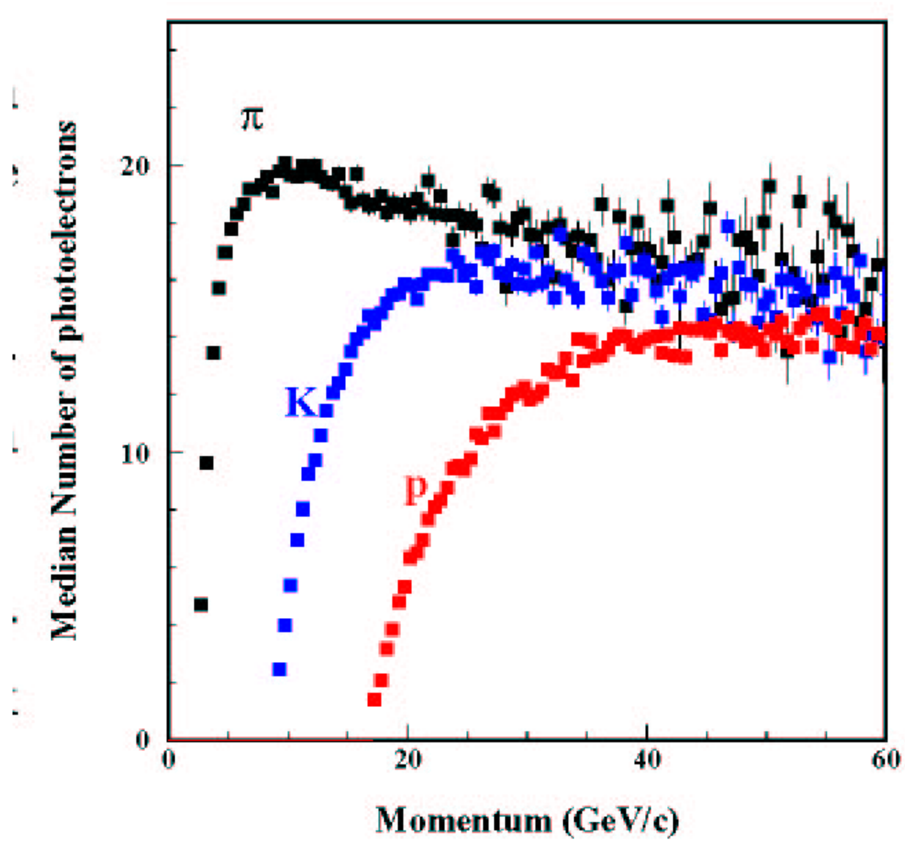

Figure 15: The median number of photo-electrons for an ensemble of tracks as a function of track momentum in the E690 Cerenkov.

types of experiments, half of the time of flight wall will be instrumented with new scintillator and phototubes allowing a better time resolution than can be obtained with recycled parts. We expect to achieve a time resolution closer to 150ps and as a result better separation for the positive particles. Using new materials for the entire detector would be cost prohibitive.

Using the Monte Carlo, the required size of the TOF detector was found to be 5m wide by 3m high. In Figure 16, the distribution of hits in the time of flight wall placed before the ROSIE magnet is shown. The particles in the momentum range of interest are spread out in the horizontal direction due to the magnetic field from the Jolly Green Giant. Furthermore, this sample represents only 78% of the particles of interest. The remaining particles pass that plane with X positions larger than displayed here, and due to the size restrictions in the Meson Hall will hit the side wall of the experimental area. This distribution suggests that we will need to cover this region up to ± 150 cm. However, the central region of the wall would cover the aperture for particles passing through ROSIE. Additional material added in the flight path of those particles will degrade the momentum resolution due to multiple scattering. To prevent this degradation, a hole is cut out of the wall corresponding to the ROSIE aperture. A second wall will be placed further down stream immediately before the RICH detector to measure the time of flight for these particles, which constitute 12% of the particles of interest. This second wall of scintillator will be discussed below.

The main requirement on the TOF is the timing resolution of the system. We assume a time resolution of 50 ps on the incident beam pulse from the beam instrumentation and use this in conjunction with the resolution on the TOF counters to obtain the separation one can expect for this detector. The particles arriving at the time of flight wall do not have a single path length but a distribution of path lengths depending upon the flight path and location of the hit. To account for these differences, the discussion of the particle identification properties of the system assumes all of the path lengths and corresponding time differences are scaled to the minimum path, 700cm. The average path length is about 790cm, so we are presenting a worst case separation. A plot of the Time vs. Momentum for the particle species is given in Figure 17, where we have assumed 200ps resolution on the TOF wall and 50ps resolution on the incident beam. The separation between pions and kaons can now be calculated for various momentum bins as shown in Table 1. Here we have calculated the separation in terms of "sigma" which is defined as the difference in the mean times, again normalized to a path length of 700 cm, divided by the sum in quadrature of the widths of the pion and kaon distributions. The width of the time distributions for a given particle type is obtained by fitting the distribution of times for a given momentum range to a Gaussian distribution. These separations show that for tracks below 1.67 GeV/c we achieve 3 "sigma" separation between pions and kaons. This range covers the crossover point for the TPC and will provide additional information at higher momenta to be used with the TPC dE/dx measurements.

With size of 5m by 3m, the TOF wall will require segmentation. When using the MINOS target with 120 GeV/c proton beam, a wall of scintillator right before the ROSIE magnet will have on average 11.2 tracks passing

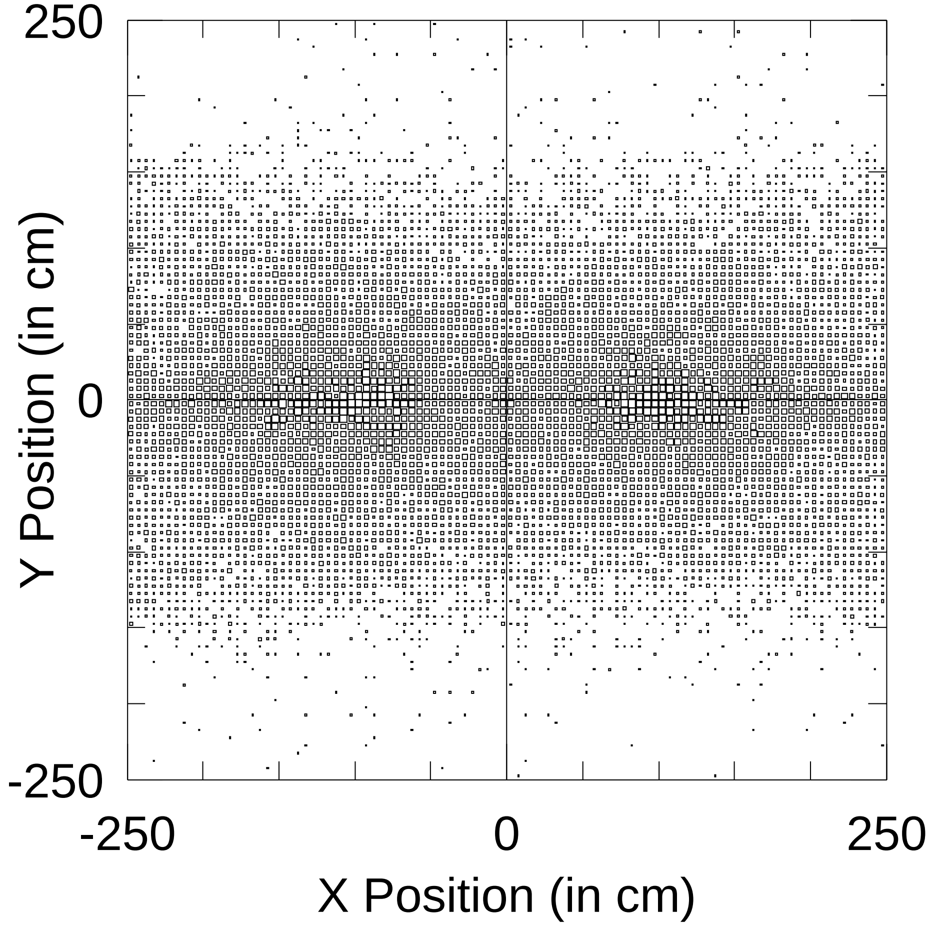

Figure 16: The distribution of hits in the Time of Flight wall placed immediately before the ROSIE magnet. Only hits from tracks with momentum between 0.7 GeV/c and 2.7 GeV/c are shown in this plot. The origin is the centerline for the beam.

through it of which 5.3 tracks will be in the momentum range between 0.7 GeV/c and 2.7 GeV/c. With this many tracks passing through the time of flight wall, the TOF detector should have segmentation fine enough to give a high efficiency for a clean hit in a counter. We assume that a second hit in a counter results in the loss of all data for those tracks. We have calculated the efficiency for various segmentations of the TOF wall. Efficiency for this wall

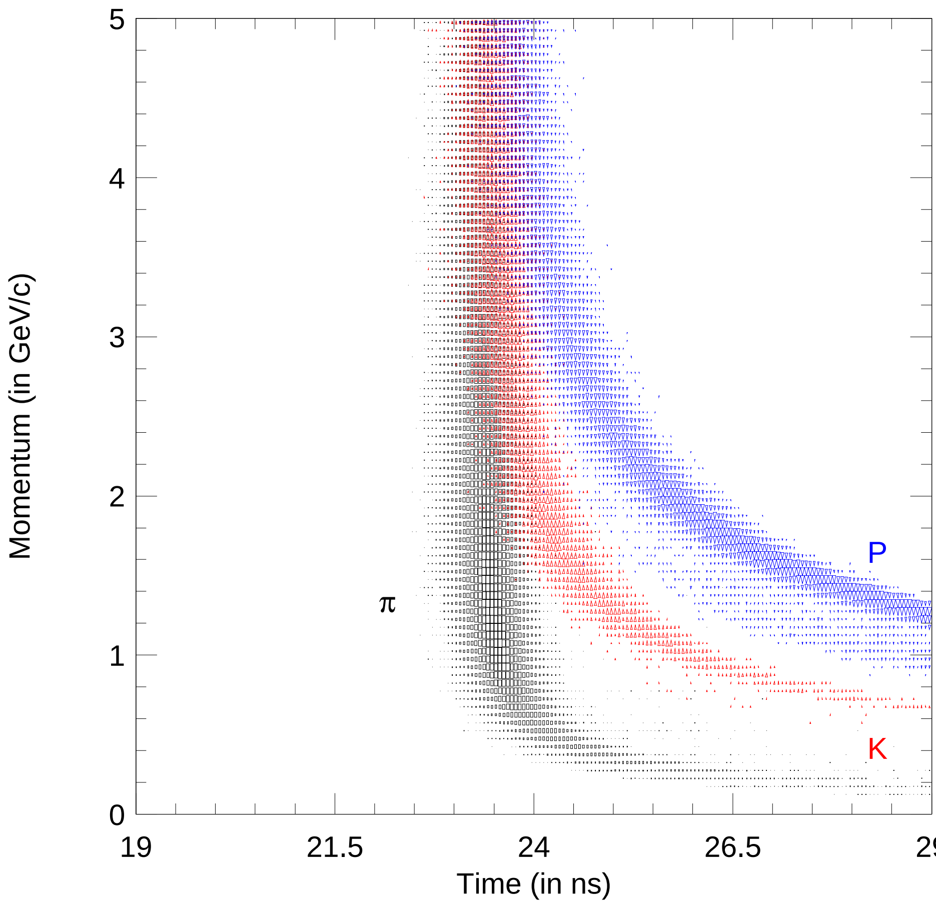

Figure 17: The normalized hit times as a function of momentum for π's in black, kaons is red and protons in blue. These times have assumed a detector resolution of 200ps on the detector and 50ps on the initial times.

is calculated as the fraction of tracks with momentum between 0.7 GeV/c and 2.7 GeV/c which are the only hit in the counter. When looking for the second hit in the counter, tracks with all momenta are considered. The efficiencies obtained for a location before the ROSIE magnet are given in Table 2. Only the results for horizontal strips, vertical strips and diagonal strips at 45^o are shown. When diagonal counters are used, the number of counters is not as easily calculated since on both edges there will be shorter counters and some part of the desired region may not be instrumented. Only an estimate is given in the table for the diagonal cases assuming a 20%

Momentum (GeV/c)	Resolution 50ps,200ps	50ps,150ps	50ps,200ps Downstream
1.0 - 1.33	4.2	4.6	6.9
1.33 - 1.67	3.2	3.8	5.3
1.67 - 2.0	2.4	3.0	4.0
2.0 - 2.33	1.8	2.3	3.0
2.33 - 2.67	1.4	1.8	2.3
2.67 - 3.0	1.1	1.4	1.8

Table 1: Separation achieved for a time resolution of 200ps on the time of flight wall and 50ps on the time from the beam. The values in the table are separations given in terms of sigmas as described in the text.

increase in the number of counters when compared to the vertical case. One can see that using counters wider than 4cm or larger with the MINOS target results in an efficiency below 90% for a single plane. This efficiency can be significantly raised with the addition of a second layer of scintillator. For example, a 90% efficiency is obtained with 10cm wide counters with two layers, one comprised of vertical strips and the other with diagonal strips at 45^o. Using this combination of scintillator strips, we need 110 strips and 220 phototubes.

The downstream station of the TOF system will sit just upstream of the RICH at 1200cm from the target. Our plan again calls for two layers of scintillator both constructed from scintillator that is 10cm wide. To cover the Rosie aperture the layers must be 2m wide by 1.3m high. The station will thus require 33 scintillator bars and 66 PMTs. The longer flight path to this station will improve the particle identification compared with the upstream detector as shown in Table 1 for the same 200ps resolution.

The final components of the detector will be the electronics. The signals coming from the phototubes need to be split with one part going to an ADC to measure the pulse heights so the time-walk correction can be applied. The remaining signal will be discriminated and passed to a TDC. The electronics are assumed to be commercial CAMAC modules. The electronics should be straight forward with the use of commercial modules thus requiring minimal electrical engineering support. These modules as well as the high voltage supplies for the photo multiplier tubes and the CAMAC crates should be available from PREP at Fermilab with little capital cost to the experiment. Cables and connectors will be searched for at Fermilab, but may need to

Single Plane							
Width	20 cm	10cm	10cm	10cm	5cm	4cm	3cm
Direction	V	H	V	D	V	V	V
Efficiency	62%	54%	77 %	71%	87%	89%	92%
Number of Counters	25	30	50	60	100	125	166
Double Plane							
Width	20 cm	20 cm	10 cm	10cm	10 cm	5 cm	5 cm
Direction	V/H	V/D	V/H	V/D	D/D	V/H	V/D
Efficiency	74 %	77%	88%	90 %	89 %	95%	96%
Number of Counters	40	55	80	110	120	160	220

Table 2: Efficiency for a clean hit in a Time of Flight counter for different orientations and widths of the counters. When looking at the direction, the H, V and D represent horizontal, vertical and diagonal respectively.

be purchased if enough cannot be found. Also the mounting assembly will have to be constructed to install the final system in the experiment. This mounting assembly will require input from a mechanical engineer.

3.7 Fixing the Jolly Green Giant Coil

One of the coils of the Jolly Green Giant magnets had developed a short during the running of the E690 experiment. We have used part of the Livermore ICO money to fix this short and repair the coil. The coil was sent to Alpha Magnetics in California for repair. When they removd the epoxy and examined the coil, they found a portion of bad conductor (see Figure 18), which was repaired. Figure 19 shows part of the coil winding and Fig. 20 shows the re-potted coil which has been shipped back to Fermilab. The total cost of fixing the coil was $69,000, including engineering oversight.

3.8 Preparation of the Experimental Hall

Working with the Fermilab management, we have identified Meson Center 7 "worm" as the appropriate place to site E907. This hall was previously occupied by the completed Fermilab experiment HyperCP. Using money from the Livermore ICO, we have cleaned out the HyperCP experiment. Fig. 21 shows the present state of MC7. We have, again using the ICO, engineered the structure needed to support the weight of the magnets Jolly Green Giant

Figure 18: Shows the portion of conductor of the Jolly Green Giant coil that was dented and caused restricted coolant flow resulting in a shorted coil.The flaw may have been present in the magnet from its initial date of manufacture in the 1960's.

and Rosy. The experimental hall below MC7, known as MBottom, had to be shored up by a steel structure engineered by Fermilab and approved by FESS. Figure 22 shows the installed steel structure in Mbottom. The floor of MC7 had to be further strengthened by means of a 1 foot thick concrete slab to spread the weight of the magnets evenly. This slab has been poured.

The addition of this slab implied a beam height of 80.5" above the floor and this required the roof of MC7 to be raised in areas downstream of the Jolly Green Giant. We have purchased the roofing material needed to do this. Further, a roll-up door had to be installed upstream of the Jolly Green Giant to move in the TPC and beam Cerenkov counters. This door has been installed.

4 Beam Requirements

The Switchyard-120 project (SY120) plans to deliver main injector beams to the Meson area for use as test beams. If P907 is approved, the beamline to

Figure 19: Shows a portion of the Jolly Green Giant coil winding during repair.

deliver beam to the experiment will also be constructed. In order to deliver test beams, one needs to be able to extract slow spill from the main injector in a well regulated fashion. The slow spill by itself will interfere with the rate of anti-proton production for the collider, since the length of the slow spill cycle must include the flat-top. P907 has come up with a scheme to extract slow spill (titled "double slow spill") where by a booster batch is given to $\bar{p}$ production at the beginning of the flat top and a portion ($\approx 10\%$) of a second booster batch is extracted to the Meson area. At the end of slow spill the remainder of this booster batch is sent for $\bar{p}$ production, thereby preserving the rate of $\bar{p}$ production. The implementation of this scheme will benefit the test beam program as well as E907, since it will increase the total amount of beam delivered to these areas by factors as large as tenfold, without adversely impacting the production of anti-protons.

The implementation of the double slow spill scheme can be achieved in a handful of shifts in the Main Injector Control room, once the slow spill extraction in the Main Injector for the test beam program has been implemented .

Figure 20: Shows the fixedJolly Green Giant coil. The coil has passed resistance and inductance tests after repair.

4.1 Changes to the E907 beam line

Due to the support structure needed for the magnets in the experiment, the beam height at the experimentral hall is 80.5in. Thus it is necessary to raise the final secondary beam to an elevation of 80.5" above the floor compared to the elevation of 49.5" of the primary beam, in order to center the secondary beam in the apertures of the two analysis magnets. To achieve this with the smallest impact on the existing target shield pile, the two bend magnets in the secondary beam have been changed to vertical bends, both upwards. The second dipole has been moved to downstream of the momentum- selection collimator, to preserve momentum recombination. Just downstream of the last quadrupole a 6-3-120 has been added which bends down. A separately powered EPB dipole just before the P907 target completes the downbend and makes the beam parallel to the floor again. To keep the BEAM Cerenkov counter lengths the same, the entire beamline has been moved 22 feet upstream. This change does necessitate a more major revision of the steel shield pile than would have been necessary if this elevation change had been unnecessary, but is achievable without having to buy any new steel. The major cost for this operation is estimated to be about one additional week of rigging

Figure 21: The downstream view of cleaned-out experimental hall MC7 in Meson Center, which used to house the HyperCP experiment.

to unweld the lower pieces of steel on the so-called “T-block” assemblies.

4.2 Running Time Requirements

If we are approved, we estimate that we would be ready to take data late in 2002. This rapid turn-on is based on our rate of progress in the past year, when, despite operating in an R&D phase, we have managed to make significant progress. Assuming that the double slow spill scheme is implemented, we estimate the following running scenario beginning in late 2002.

A 3000 hour year allows for 24 “data points”. The calculation of the time required for the various parts of the experiment are shown in Table 3. Note that the H_2 target running is with a 2% target and higher beam flux at high momentum. Our calculated run time for the first run is 3250 hours.

This takes us into the middle of 2003. At this point, we would be well-positioned to measure the production spectrum off a MINOS target with a well-debugged detector running smoothly. We estimate a 3.3 data point run for a MINOS target yielding 10^7 events. This phase of the experiment is expected to take $\approx$ 400 hrs. It must be emphasized that slowspill from

Table 3: Running time requirements for various aspects of E907 running.

Target	"Physics"	Beam Energies	Beam Charges	factor (3×10^6 events/data point)	data points
Cu	Engineering run	3	2	0.5	3.0
H_2	scaling	12	2	1.0	24.0/4
N_2	atm. ν	3	2	0.5	3.0
O_2	atm. ν	3	2	0.5	3.0
Be	p-A	1	1	2.0	2.0
Be	survey	5	2	0.1	1.0
C	survey	5	2	0.1	1.0
Cu	p-A	1	1	2.0	2.0
Cu	survey	5	2	0.1	1.0
Pb	p-A	1	1	2.0	2.0
Pb	survey	5	2	0.1	1.0
Various	Nucl. scaling	5	2	0.1	1.0
total					26.0

Figure 22: The experimental Mbottom area beneath MC7 has been strengthened by this steel structure in order to support the magnets Jolly Green Giant and Rosy

the Main Injector is far easier to acquire when only the Tevatron is a Main Injector customer. As soon as MINOS starts running, it will reduce the rate of $\bar{p}$ production by 40% on its own. Slowspill running is best done before MINOS startup.

5 Project Mangement

5.1 Cost and Schedule Plan

In November 2000 we completed a zero'th order draft cost and schedule plan. [3]

Here we will summarize the major assumptions and conclusions of that plan, the progress we've made in the past year executing the plan, and the major changes and additions. We are currently revising the plan and expect to release a new version shortly.

5.1.1 Cost and Schedule Plan Summary

The November 2000 Cost and Schedule Plan contains a complete cost, manpower, and schedule estimate for E907. By "complete," we mean we have covered all systems and sub-systems of the experiment, including the upstream beamline. We also included removal of existing equipment from the Meson Center area of the detector building and the worm which houses HyperCP, to make way for this experiment. The work breakdown structure (WBS) is shown with our estimate basis. On the manpower side, we have estimated the level of physicist, engineer, and technician effort required to design, install, commission, operate, and analyze the experiment. We have estimated the engineering effort by discipline, mechanical or electrical. We have separated engineering and technician effort. We have included physicist effort in order to understand the size of collaboration required. We have also made preliminary estimates of the number of physicists that will be required to operate the experiment during data running and to perform the basic analysis.

In summary, the major items and cost rollups are shown in Table 4. The manpower estimate amounts to approximately 12 physicist years, 1.5 engineer years (split equally between mechanical and electrical), and 5.5 technician years.

The following subsections discuss the scope of the estimate and the estimate method and basis.

5.1.2 Scope of Estimate

Almost all experiment systems are based on existing equipment. By using existing systems with proven performance we eliminate the detector research and development phase, drastically shortening the design cycle and reducing the experiment cost. The engineering and design process for these systems is largely limited to "infrastructure" issues: mounting, installing, connecting electrical and other services, and data cabling.

At this time we have not located a suitable existing detector that could function as our time-of-flight (TOF). As a placeholder we included ~\$30k for installation, pending location of a suitable existing system.

Since we will run with both 120 GeV/c primary beam from the Main Injector (MI), as well as 5–105 GeV/c secondary beams, the upstream beamline is not trivial. Initially, we included the costs associated with designing

Table 4: Work breakdown structure (WBS) and cost rollup. We assume that physicist effort is not charged directly to the experiment; tasks with zero direct cost are to be done by physicists.

WBS	Task Name		Cost ($K)
	Fermilab E907		1,069.0
1.0	Experiment Design		0.0
2.0	Meson Center Preparation		129.3
3.0	E907 Beamline (BEAM) in MC6		131.3
4.0	Meson Worm (MC7) Preparation		59.6
5.0	E907 Experiment		741.6
5.1	Upstream Beamline Detectors (UBL)	33.8	
5.2	Experimental Targets (ETGT)	33.9	
5.3	Target Recoil Detector (TRD)	32.9	
5.4	Time Projection Chamber (TPC)	50.4	
5.5	Jolly Green Giant (JGG)	96.3	
5.6	Differential Cerenkov (CKOV)	69.2	
5.7	Time-of-Flight (TOF)	27.0	
5.8	TPL-B Magnet (TPL-B)	36.3	
5.9	Ring Imaging Cerenkov (RICH)	144.9	
5.10	Drift Chambers (DC)	137.2	
5.11	Neutral Hadron Calorimeter (NCAL)	27.0	
5.12	Trigger (TRG)	13.2	
5.13	Data Acquisition (DAQ)	19.4	
6.0	Data Taking (DATA)		0.0
7.0	Core Analysis		0.0
8.0	Project Management		0.0

and constructing this beamline as part of our plan. However, with the decision not to proceed with KaMI, Beams Division has agreed to redirect the SY120 AIP (Accelerator Improvement Project) funds which had been planned for the KaMI beamline. Instead, Beams Division plans to construct our upstream beamline in FY02.

Meson Center was most recently used by E871 (HyperCP). A certain amount of disassembly and cleanout is required before this experiment can be installed. We included an estimate for this work.

5.1.3 Estimate Method and Basis

Since most detector systems are based on existing hardware, most of the WBS items require a fairly detailed understanding of the component designs and infrastructure requirements to produce detailed designs for costing. Therefore, at this stage cost estimating has been limited to known costs of similar recent tasks and engineer or physicist estimates, generally at WBS level three. In the past year, we have made substantial progress on detailed understanding of most of the detector systems. We are currently incorporating that understanding in a revised cost and schedule plan.

For each task,we separately estimate the level of effort required from physicists, engineers, and technicians, and the materials and supplies. We use nominal Fermilab rates, including fringe benefits, for engineers and technicians, as provided by John Cooper. We assume that physicist effort is not charged directly to the experiment, however the level of physicist effort required *is* part of the estimate (see the discussion of manpower, below).

Where possible, the estimates have been based on known effort and costs for similar tasks accomplished in the recent past. Tasks and costs for rigging and magnet connections/disconnections were developed with the generous assistance of Leon Beverly and Mike Mascione in PPD, based on recent work in MC6, MC8, and Lab G. Before the last run of the HyperCP experiment, an access was made to the MC6SWP magnet in the upstream subsection of the MC6 Target Pile. This effort forms the basis for the estimates in WBS 2 and 3 for opening and closing the MC6 Pretarget Enclosure and Target Pile. In 2000 a T&M rigging contract work was used to remove the Jolly Green Giant and a second large magnet from Lab G, which forms the basis for the estimate to reassemble the Jolly Green Giant and Rosy magnets in the MC7 worm. The Jolly Green Giant magnet had a short in one of the coils that developed when it was moved from Brookhaven to Fermilab circa

1990 for E690. In 1991 the E690 experimenters obtained a budgetary quote of \$55k to build a replacement coil. Suitably adjusted, this forms the basis for replacing the coil. The costs of opening and closing the MC7 worm roof to enable crane access for the magnet assembly are based on the actual costs incurred in opening and closing the MC8 worm roof to extract steel shielding blocks. The effort to extract the RICH was estimated by Mike Mascione, who was the supervisor when it was installed in PC4.

For more details, and a discussion of the manpower estimate and contingency, please see the draft Cost and Schedule Plan.

5.1.4 FY2001 Work Planned and Accomplished

With the support of Fermilab management, we decided to proceed with four items in FY01:

- WBS 4.0 Meson Worm (MC7) Preparation
  Remove the HyperCP detectors and magnets from the MC7 worm.
- WBS 5.5 Jolly Green Giant (JGG)
  Repair the JGG coil and install JGG in the MC7 worm.
- WBS 5.8 TPL-B Magnet (TPL-B)
  Install TPL-B in the MC7 worm.
- Resurrect the TPC in a test area and demonstrate readout of cosmics.

This work was funded by ICO (a purchase contract) from LLNL to Fermilab, in the amount of \$228K.

The MC7 worm has been completely cleaned out All HyperCP detectors have been removed (with the exception of the neutral calorimeter, which we intend to reuse). The analyzing magnets, steel and concrete blocks, and shielding have been removed.

We decided to use the Rosy magnet, from DONUT, instead of the TPL-B magnet, since it had superior field and aperture qualities.

We placed a contract for repair of the JGG coil, for significantly less than we budgeted (\$60K). However, the repair proved to be somewhat more involved than the contractor anticipated. The repair is complete, and the final cost, including engineering oversight, is \$65K.

Further analysis of the beam tagging Cerenkov counters showed that they require significantly more length than we originally anticipated. This change has pushed the experiment to the downstream end of the MC7 worm, over the Meson Bottom tunnel. We spent considerable effort to understand the engineering issues of placing the large analyzing magnets on the subpar floor reinforcing, weak soil, and the MBottom tunnel.. This resulted in two major new tasks, designing, fabricating, and installing steel shoring in MBottom and pouring a large concrete slab in MCenter. These tasks replaced the magnet installation tasks originally planned for this fiscal year. These tasks are complete. The magnets will be installed early in FY02.

A second consequence of the work to support the magnets is that we have had to raise the beam elevation. This further requires that we raise the MC7 worm roof. The design work has been completed, FESS has approved the roofline change, and the materials purchased. The installation will take place after the magnets are installed.

The TPC work has gone quite smoothly in the MTest area; see that subsection for details.

5.1.5 Major Changes to the Cost and Schedule Plan

A number of major changes have already been discussed; the likely cost impacts are summarized here.

- Beams Division has agreed to build our beamline as part of the SY120 AIP project, removing \$261K of work from our plan (WBS 2 and 3).
- The shoring, slab, and roof modifications in MC7, required by the location of the experiment over MBottom, will appear in the revised plan. The approximate additional cost is \$73K; final costs will be known in the next two months.
- We now have a realistic plan for the Time-of-Flight, using existing components augmented by new components in the critical regions. This plan requires \$133K more than we originally budgeted.
- The Rosy magnet will be substituted for TPL-B; this has negligible impact on cost and schedule.
- The RICH front end electronics have to be rebuilt. A very preliminary estimate is \$50K in chips, plus design, test, and installation.

- We have identified the HyperCP calorimeter as suitable for our neutral calorimeter. We had previously budgeted \$27K for installation; this number will not change significantly.

On balance, the total of these changes is approximately cost neutral. A revised cost and schedule plan incorporating these changes will be available shortly.

5.2 Funding Sources

The FY01 activities were funded by an ICO (Integrated Contractor Order) from LLNL to FNAL, in the amount of \$228K.

As discussed in the previous section, the additional work incurred to support the magnets over the MBottom tunnel, and the increased cost of the time of flight system, are approximately equal, leaving ∼\$750K of remaining work to install E907.

LLNL has indicated that, upon signing of an MOU between LLNL and FNAL, they anticipate being able to fund up to ∼\$500K to support E907 activities at FNAL in FY02, with additional funds available in FY03. In addition, as already discussed, Beams Division will fund the upstream beamline work (∼\$261K) in FY02 from the SY120 AIP project.

Because of the increased scope of work in FY01, some tasks will have to be completed in FY03 if we rely solely on LLNL funding. This is a possible fallback funding scenario.

We are actively pursuing additional funding sources for FY02. The DoE National Nuclear Security Administration has just announced a Stockpile Stewardship Academic Alliances program to fund experimentally-oriented university proposals aimed at enhancing academic participation in stockpile stewardship activities. Particle production data from E907 is relevant to the proton radiography activity of the Stockpile Stewardship Program, as we discussed in the E907 proposal. All work funded through this new program will be strictly unclassified and may be published in the open literature.

We also expect a small amount of funding to construct the experiment from the collaborating Universities (Columbia, Chicago, Michigan, South Carolina, Houston, and Coloroda) at the level of ≈200K. This funding can only be secured following scientific approval of the experiment.

Table 5: Working group membership in current R&D phase of P907

Group Activity	Members
TPC Hardware	P.Barnes, B.Cole,R.Soltz
Data Acquisition	R.Soltz,M.Heffner,D.Asner,B.Cole+
	CD group: M.Votava,D.Slimmer,L.Piccoli
ToF System	T.Bergfeld,A.Godley,S.Mishra,C.Rosenfeld
Chambers	B.Mayes,R.Pinsky, J.Peterson,J.Brack
E690 Cerenkov	E.Hartouni, D.Asner, D. Wright
RICH	E.Swallow, R.Winston
Monte Carlo	J.Gronfeld, D.Lange,R.Raja
Beam Cerenkovs	T.Murphy,G.Koizumi,M.Heffner
Calorimeter	H.Gustafson, M.Longo
Floor Management	L.Beverly and group

5.3 R&D working groups

We list in table 5 the working groups active during the current R&D phase of P907. We have managed to make considerable progress with an enthusiastic group of physicists. We have tried to get funding from DoE-Nuclear physics to hire post docs and support graduate students for both the University of Houston and the University of Colorado groups. This request has not been fulfilled to date, primarily due to the fact that P907 has not received scientific approval. Also, other groups are on the verge of joining the experiment but would like to await the PAC recommendation. In order to strengthen the collaboration further, one needs to go beyond the present “chicken and egg” state of affairs.

If approved, the Universities of Chicago, Columbia, Michigan and the Fermilab groups expect to add post postdocs to the experiment.

6 Appendix

We include here the contents of a p-A whitepaper, co-written by Sam Aronson and Jen-Chieh Peng. It was the result of a APS-DNP town meeting held at BNL, Oct 28-29, 2000. This workshop was one of two held under the topic QCD at RHIC. The announcement and agenda (with some transparencies) are given by the following two links.

- http://www.bnl.gov/rhic/townmeeting/qcd_first.htm
- http://www.bnl.gov/rhic/townmeeting/agenda_b.htm

White Paper on Proton-Nucleus Collisions

1) Introduction and Recommendations

The role of proton-nucleus (p-A) collisions in the study of strong interactions has a long history [1]. It has been an important testing ground for QCD [2, 3]. At RHIC p-A studies have been recognized since the beginning as important elements of the program. These include so-called baseline measurements in cold nuclear matter, essential (along with p-p studies) to a systematic study of QCD at high temperatures and densities in the search for the quark gluon plasma. Also accessible is a study of QCD in the small x (parton saturation) regime, complementary to physics accessible in high-energy e-p and e-A collisions [4].

The role of p-A physics at RHIC was reviewed and brought into sharp focus at a workshop conducted in October 2000 at BNL; the agenda is shown in Appendix 1. This document summarizes the case for p-A at RHIC during the period covered by the next Nuclear Physics Long Range Plan. In subsequent sections we cover the Physics Issues, Experiment Run Plans and Schedule, Detector Upgrade Issues, and Machine Issues & Upgrades.

We conclude this section with a list of the principal recommendations for the RHIC p-A program:

- The highest priority is to implement a run plan for RHIC that includes significant p-A and/or d-A running starting in the third run (FY2003) and continuing during the next several running periods thereafter. This requires that some machine development time in FY2002 be devoted to commissioning p-A and/or d-A collisions in RHIC. Plans for FY2003 and beyond should be based on integrated luminosity per nucleon in proton-nucleus comparable to that obtained in proton-proton and nucleus-nucleus running conditions.

- Second priority is to develop and implement detector upgrades over the next 3-5 years that allow a more complete study at RHIC on the physics of cold nuclear matter at small x. This includes forward detectors for tagging, diffraction measurements and Drell-Yan measurements at very small x. Modest R&D funding to anticipate these detector upgrades should be planned starting in FY2002.

- As indicated in Section 7 below, the p-A program can benefit from machine improvements including asymmetric running, higher luminosity and higher energy. Therefore the third priority is to develop the machine capabilities to provide these running conditions. This includes interaction triggers and luminosity measurement (and monitoring) that can cope with asymmetric IR geometries. Some of these machine developments will require upgrades to the accelerator (e.g., electron cooling of the ion beam) that may be realized only in the 5-year period after the next one.

2) Significance of p-A Physics and Scientific Questions to be Addressed

The advent of the Relativistic Heavy Ion Collider (RHIC), the primary goal of which is to investigate matter at extraordinary temperature and energy density via nucleus-nucleus collisions, will also offer a unique opportunity to study some fundamental questions in strong interactions via p-A collisions. It is important to point out that RHIC, for the first time, will allow us to study p-A interaction in a collider mode. At RHIC, the center-of-mass energy reached in p-A collisions is roughly an order of magnitude higher than any existing fixed-target experiments. Moreover, the large-acceptance collider detectors are capable of measuring many particles produced in the p-A collisions simultaneously, which could provide qualitatively new information not accessible in previous fixed-target experiments.

It has long been recognized that p-A collisions serve an important role in the search for quark-gluon plasma (QGP) in relativistic heavy-ion collisions. Since QGP is in general not expected to be produced in p-A collisions, a comparison of the A-A with p-A data at identical kinematic conditions is crucial for identifying signatures for QGP formation. This was clearly demonstrated in the AGS and SPS heavy-ion programs, which relied heavily on the p-A measurements for interpreting the A-A results. This important role of p-A collisions is clearly valid at RHIC too.

In addition to their connection to A-A physics, the p-A measurements are important in their own right. Many outstanding questions in hadron physics can be well addressed with an active p-A program at RHIC. These questions include:

- What are the valence and sea quark and gluon contents in nuclei? How are they different from those in a free nucleon?
- How do high-energy partons propagate through nuclei? Can nuclei be used as a tool to study space-time evolution of QCD processes?
- Do parton densities saturate at small x? Can they be described by the conventional DGLAP evolution equations at the small-x region?
- What are the sub-structures of Pomeron and mesons? What are the roles of mesons in describing the partonic structures of nucleon and nuclei?

In this document, we will discuss how these questions can be addressed at RHIC and other accelerators with p-A collisions.

3) Achievement Since Last Long-range Plan

Several fixed-target p-A experiments have been successfully completed at Fermilab, CERN-SPS, and AGS. Some highlights from these experiments together with progress in related theoretical work are:

- A series of p-A dimuon production experiments have been carried out at Fermilab in the last decade using 800 GeV proton beams [3]. From the measurement of Drell-Yan cross section ratios of $(p+d)/(p+p)$, Fermilab E866 experiment clearly established the flavor asymmetry of the up and down quarks of the nucleon sea [5] (see Fig. 1). This result strongly suggests that the meson degrees of freedom are important for understanding the parton structure of nucleons. Several theoretical models including meson-cloud, chiral-quark, chiral-quark-soliton, and instanton models have been proposed to explain this asymmetry [6]. These models have distinct predictions for the spin and flavor structure of nucleons, which could be tested in experiments in the near future.

- Recent theoretical work on the propagation of high energy partons through cold and hot nuclear matter predicted a number of surprising effects [7]. First, the total amount of radiative energy loss (through gluon emission) of a parton is predicted to be proportional to L^2, where L is the path length traversed by the parton inside the nuclear matter. This result is contrary to the conventional wisdom that energy loss depends linearly on L. Second, the partonic energy loss in a hot QCD plasma is predicted to be much larger than in a cold matter, suggesting the use of jet-quenching as a signature for QGP formation [8]. The nuclear dependence of Drell-Yan cross sections in 800 GeV p-A collisions was recently analysed to extract information on partonic energy loss in cold nuclear matter [2]. These Drell-Yan data also showed clear evidence for nuclear shadowing of the sea-quark distributions at low x ($x \sim 0.01$).

- Pronounced nuclear effects of charmonium J/Ψ and Ψ' production as a function of longitudinal momentum x_F and transverse momentum p_T were observed in 800 GeV p-A interactions [9] (see Fig. 2). The polarization of J/Ψ and Υ resonances has also been measured recently [10]. The $\Upsilon(2S+3S)$ states were observed to possess large polarization, in striking contrast with the $\Upsilon(1S)$ state.

- Fermilab E791 very recently reported the first measurement of pion's light-cone wave functions by detecting di-jets produced in a diffractive dissociation process [11]. The nuclear dependence of this process has been interpreted as evidence for color-transparency [12]. This study could readily be extended at RHIC to measure the proton's light-cone wave functions via the detection of three jets.

- Several p-A experiments have been carried out at the CERN SPS. The CERES/NA45 and TAPS collaborations have measured low-mass electron pairs in p-Be and p-Au collisions at 450 GeV/c [13]. NA50 measured muon pairs produced in p-Al, p-Cu, p-Ag, and p-W collisions at 450 GeV/c [14]. WA97 measured strange particles production in p-Pb collision at 158 GeV/c [15]. These p-A measurements were crucial for identifying abnormal behavior in A-A collisions such as J/Ψ-suppression, enhancement of strange particle production, and the excess of low-mass lepton pairs.

- Several dedicated p-A experiments have been completed recently at the AGS. In particular, the E910 experiment showed that the centrality and the number of collisions in p-A interaction could be well characterized by the total number of "gray" tracks emitted in a given event [16]. Many observables were found to correlate strongly with the multiplicity of the "gray" tracks. The detection of "gray" tracks is feasible at RHIC, and should be very useful for understanding the p-A and A-A results.

4) Opportunities and Plans for the Future

In the near future, p-A physics can be pursued at two recently commissioned accelerators – RHIC and the Fermilab 120 GeV Main-Injector (FMI). In the longer-term future, the CERN LHC and the 50-GeV Japan Hadron Facility (JHF) will provide additional venues for p-A physics.

The p-A physics opportunities at RHIC include:

1. Probing the parton distributions in nuclei at small x

   - Di-leptons from the Drell-Yan process are sensitive to antiquark distributions in nuclei. For 100 GeV (250 GeV) protons colliding with 100 GeV·A nuclear beams at RHIC, one will be able to reach values of x down to 1×10^{-3} (5×10^{-4}). This will extend the current reach in low x by roughly two orders of magnitude. Figure 3 shows the kinematic coverage in x and the expected statistical accuracy for a two-month run at PHENIX. Qualitatively new information on the sea-quark content in nuclei, such as shadowing and non-linear saturation effects, could be revealed. In principle, saturation effects for high-density partons at small x could also be searched for in the p-p or e-p collisions. However, by using a heavy nucleus in e-A or p-A collisions, the onset of the saturation effects can occur at a much larger value of x due to the $A^{1/3}$ enhancement factor for the partonic density. The flavor asymmetry of sea-quark distributions in the nucleon could also be explored to very low x.
   - The nuclear dependence of the gluon distribution is practically unknown. At RHIC, the gluon content of the nucleus at a wide range of x could be measured using a variety of hard processes [17], including direct-γ production, γ-jet production, di-jet production, heavy-quark production, high-p_T single-muon production, and low-mass high-p_T dimuon production [18]. Indeed, any

hard processes suitable for extracting gluon polarization information in the RHIC-spin program would also be ideal for probing the nuclear gluon distributions in p-A collisions. These results will provide new information on the gluon content of nuclei, which is closely connected to one of the physics goals of a possible future e-A collider.

- Parton distributions in nuclei provide essential input for predicting interesting observables in heavy-ion collisions. In particular, cross sections for mini-jet production and for other hard processes depend sensitively on how the parton distributions are modified in nuclei (as compared to those in nucleons) [19]. Therefore, the study of quark and gluon shadowing in nuclei is crucial for interpreting A-A collision results. [20].

2. Hard diffractive processes

   - The collider kinematics coupled with large-acceptance detectors at RHIC is ideal for studying semi-inclusive process where particles emitted in coincidence with a hard process are detected. One example is the hard diffractive process that was studied extensively at the HERA e-p collider [21] and at $\bar{p}-p$ colliders [22]. By detecting forward-going energetic neutrons or protons in coincidence with a hard process such as deep-inelastic scattering or di-jet production, information on the partonic structures of Pomerons and/or mesons were obtained at HERA [23]. At RHIC, hard diffractive processes can be studied for the p-A system for the first time. Unique information such as the nuclear dependence of the hard-diffractive process could be obtained. The interesting relation [21] between diffractive processes and small-x physics could be further explored. Moreover, the polarized beam at RHIC offers a unique opportunity to study spin-dependence of the diffractive process.
   - The recent measurement [11] of the light-cone wave function in pions using the diffractive dissociation method can be readily extended at RHIC by scattering proton beam off nuclei. The signals will involve two or three jets emitted along the proton beam direction carrying most of proton's momentum [24]. The Fock space q^3 as well as the q^2q components of the proton can be determined. The role of color transparency in the production of coherent forward jets can be further studied.

3. Polarized protons

   - P-A physics with polarized protons and possibly also with polarized light nuclei such as d, ^{3}H, ^{3}He and ^{19}F provides an additional approach [25]. For example, these measurements can study spin dependence in the EMC effect. $\vec{p}+\vec{n}$ interaction can be measured with $\vec{p}$ colliding with polarized ^{3}He or deuteron beams. RHIC's spin and p-A capabilities together result in a unique high-energy facility.

The 120 GeV FMI and the planned 50 GeV JHF are ideal for studying parton distributions in nucleons or nuclei at large x ($x > 0.2$) (see Fig. 4) and are very much complementary to the p-A program at RHIC. Experience from the RHIC p-A program will also be very valuable for planning p-A experiments at LHC.

5) Experiment Run Plans and Schedule

All the RHIC experiments have long-standing plans to perform comparison runs with existing detectors as part of the systematic study of hot and dense nuclear matter. Examples of comparison measurements and of fundamental QCD measurements have been listed in the previous section.

Some general features of a comprehensive p-A program can be inferred from the plans of the four RHIC experiments as presented [27] at the Workshop:

- p-A running ought to be available in FY2003. Machine studies, discussed in the next section, need to be planned in time for the demands of the p-A program, i.e., not later than the 2002 RHIC run.
- Sufficient statistics for comparison p-A running may require calendar time on the same order as p-p and A-A running. Depending on the merits of the physics case for fundamental QCD measurements outlined in this report, one could foresee future RHIC runs that are largely dedicated to p-A.
- The ability to run p-A with protons in either the blue or the yellow ring is still important. The current RHIC experiments all have interests and capabilities here but all have "upstream-downstream" asymmetries to a greater or lesser extent.

6) Detector Upgrades

Some physics topics available with p-A collisions benefit from upgrades to the present RHIC detectors. The most commonly identified upgrade is forward tagging. These would comprise "Roman Pot" detectors in the outgoing beam directions. They can be used to detect forward-going baryons to select specific proton-meson processes. This is straightforward and not very expensive technology, already being employed at RHIC in the p-p total cross-section measurement [28]. The forward-tagging of the nucleus would be a much more challenging task. Some preliminary design consideration has been presented in the context of the e-A collider [29].

More extensive upgrades aimed at p-A physics involve new or enhanced detector systems. For example, measurement of Drell-Yan production in PHENIX as presently configured is limited to $x_2 \geq 10^{-3}$ by the acceptance of the muon spectrometers. To extend the x_2 coverage to the kinematic limit, a small very forward angle di-muon spectrometer was suggested [30] at the Workshop. In another example, both STAR and PHENIX considered [31] high precision vertex trackers for open charm measurements. These are presumably the same vertex tracking detectors that those experiments are considering for enhanced charm measurements in the A-A program. Both the forward muon spectrometer and the precision vertex detectors are major projects, comparable in cost and timescale to the detectors funded under the RHIC AEE program (i.e., of order \$5M - \$10M and 5 years).

Although there is currently no new additional experiment proposed, it is foreseeable that a dedicated p-A experiment in the future with an emphasis on forward/backward detector coverage for exclusive channels may provide unique physics opportunities beyond the existing RHIC experiments.

7) Machine Issues and Upgrades

The pA Workshop brought to the fore a number of areas of accelerator development that are particular to p-A physics [32]:

- IR geometry - at equal energies per nucleon proton and heavy ion beams have different magnetic rigidities. Head-on p-A collisions require the beams to be angled by several milliradians relative to the trajectory for equal species. This requires the DX magnets to be moved and has negative implications for the acceptance of the present zero-degree calorimeters in RHIC.
- Asymmetric running - at equal magnetic rigidity, proton and gold beams have about 250 and 100 GeV/nucleon respectively. This has advantages for extending measurements to higher $\sqrt{s}$ and lower x. It also leaves the DX magnet position and ZDC acceptance untouched. However, there are questions yet to be resolved about how to fit these two orbits of different energy into the RHIC aperture.
- Many of the proposed measurements could benefit from an increase of the beam luminosity by a factor of 3-5.
- d-A instead of p-A - deuterons are much closer in Z/A to heavy ions than are protons, so some of the above issues are moot with deuterons. They would also provide separate p-A and n-A information with appropriate tagging of the spectators. Deuterons would also provide comparison running (i.e., at 100×100 GeV/A) with nearly the same IR geometry as p-p and A-A. However the acceleration of deuterons in RHIC requires work on the ion source and the new RFQ. The pros and cons for the three possible running modes are shown in Fig. 5.

It seems likely that both asymmetric p-A running and d-A running at 100 GeV/A will be highly desirable and preferable to p-A at 100 GeV/A for many applications. The issues enumerated above in this section require machine studies and some R&D. As mentioned in the previous section, the experiments would like to begin accumulating nucleon-nucleus data by 2003 at the latest, so these studies and R&D efforts should be incorporated into RHIC planning very soon.

Appendix 1

This agenda and links to many of the talks presented at the Workshop can be found at:

http://www.bnl.gov/rhic/townmeeting/agenda_b.htm

Workshop on pA Physics at RHIC

Saturday, October 28, 2000

Chair: P. Paul

1:30 - 1:35	Introduction, Purpose of the Workshop	S. Aronson
1:35 - 2:15	pA Physics and Relation to AA at RHIC	X. N. Wang
2:15 - 2:45	Color Glass Condensate	R. Venugopalan
2:45 - 3:25	QCD and pA Physics at RHIC	M. Strikman
3:25 - 3:40	Coffee Break	

Chair: L. McLerran

3:40 - 4:10	eA Physics	W. Krasny
4:10 - 4:40	pA Physics and Relation to eA	G. Garvey
4:40 - 5:10	Recent Results from pA	B. Cole
5:10 - 5:40	Results from CDF	A. Bhatti
5:40 - 6:00	Comments on experimental study of the CGC	R. Seto
7:00	Dinner at Senix Creek Inn	

Sunday, October 29, 2000

Chair: R. Tribble

9:00 - 9:30	Polarized pA Physics at RHIC	H. En'yo
9:30 - 10:00	Small-X and Diffractive Production at RHIC	J. Peng
10:00 - 10:30	Gluon Shadowing and Direct γ Production	P. Stankus
10:30 - 10:45	Coffee Break	

Chair: B. Jacak

10:45 - 11:25	Plan for pA Measurements at PHENIX	M. Brooks
11:25 - 12:05	Plan for pA Measurements at STAR	P. Jacobs
12:05 - 1:15	Lunch Break	

Chair: T. Ludlam

1:15 - 1:45	Plan for pA Measurements at BRAHMS	F. Videbaek
1:45 - 2:15	Plan for pA Measurements at PHOBOS	A. Carroll
2:15 - 2:50	pA Accelerator Issues	D. Trbojevic

2:50 - 3:20	Diffractive Production, Luminosity, and Forward Tagging in pA at RHIC	S. White
3:20-3:45	Coffee Break	
Chair: S. Aronson		
3:45 - 5:30	Discussions (run plans, detector issues, other physics topics, input to long-range plan etc.	All Participants
	Comments on pA opportunities at RHIC	H. Huang
	Cronin effect via p_T enhancement in pA collisions	G. Fai
5:30	Workshop Adjourned	

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[32] S. White and D. Trbojevic, talk presented at the "Workshop on pA Physics at RHIC," BNL, October 28-29, 2000.

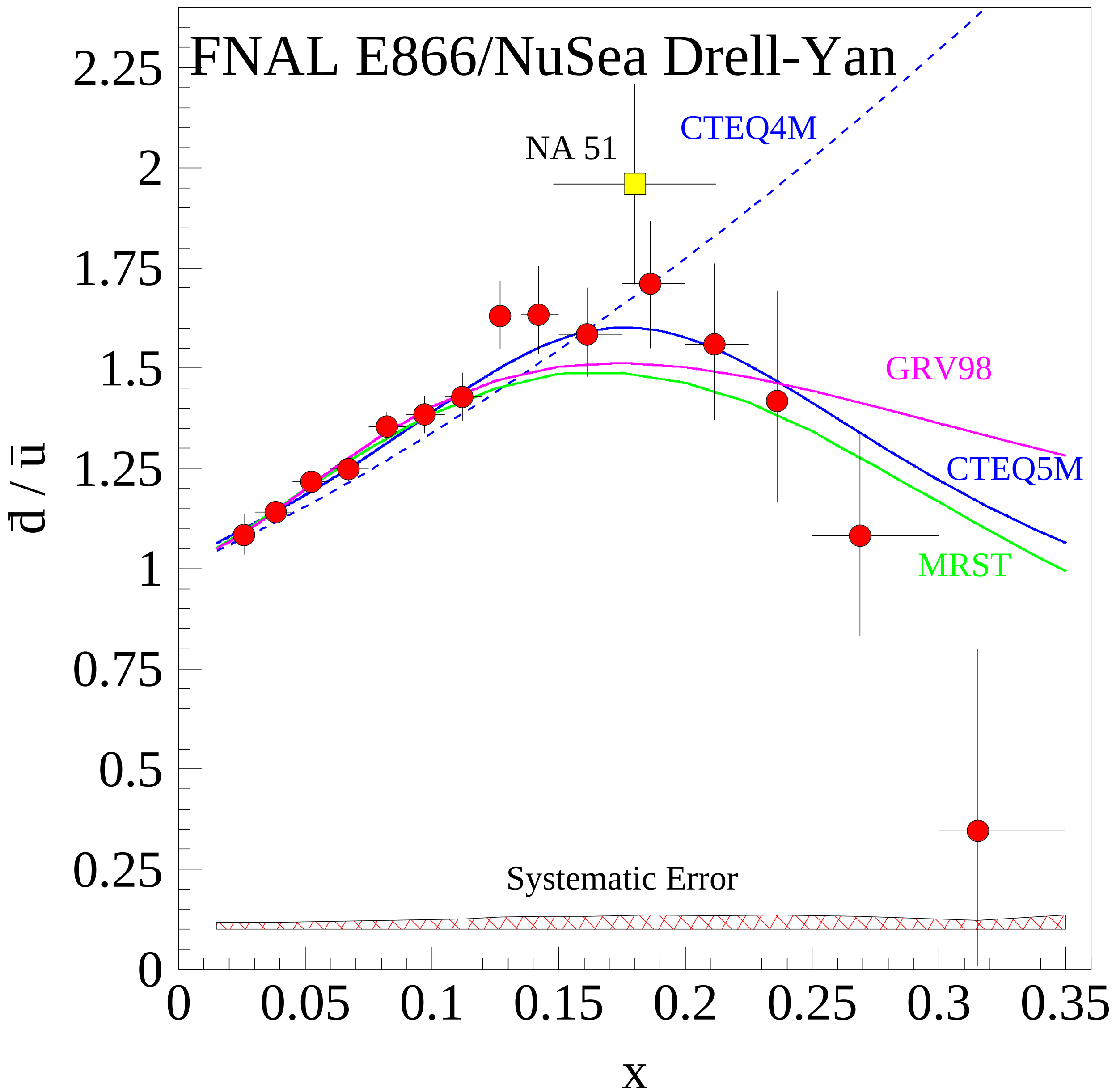

Figure 1: E866 data on $\bar{d}(x)/\bar{u}(x)$ versus x are compared with parametrizations of various parton distribution functions. The data point from NA51 is also shown.

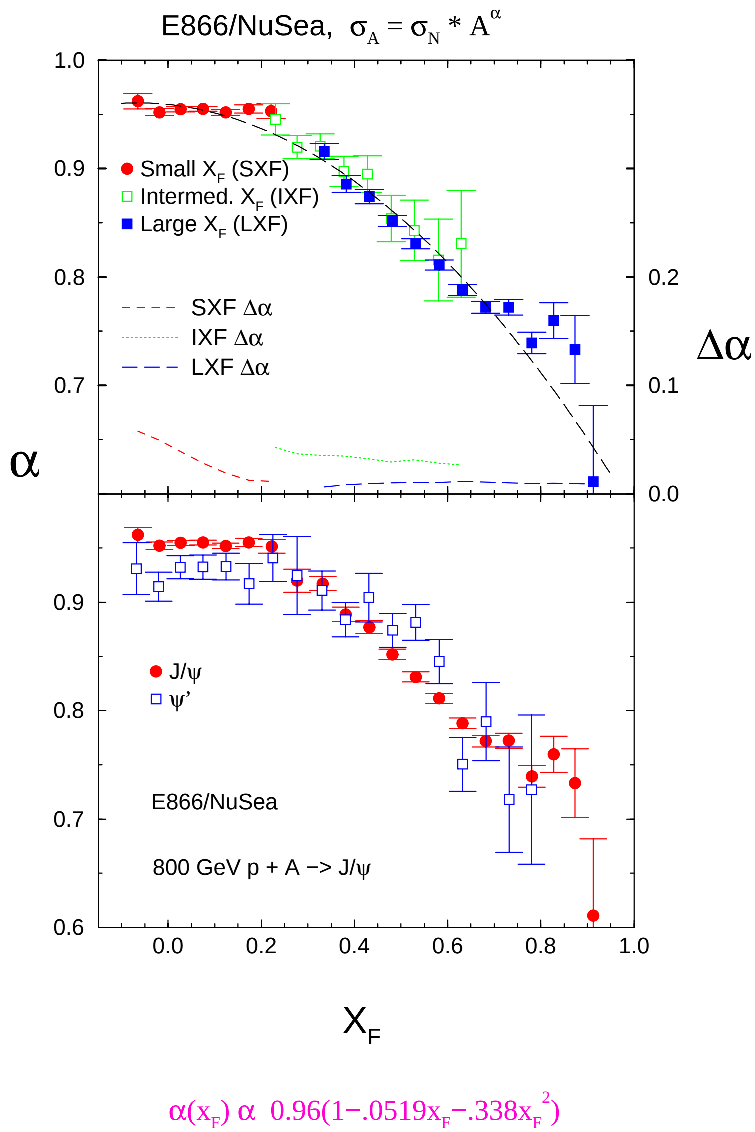

Figure 2: Nuclear dependences for proton-induced J/Ψ and Ψ' production at 800 GeV/c. Data are from Ref. [9]

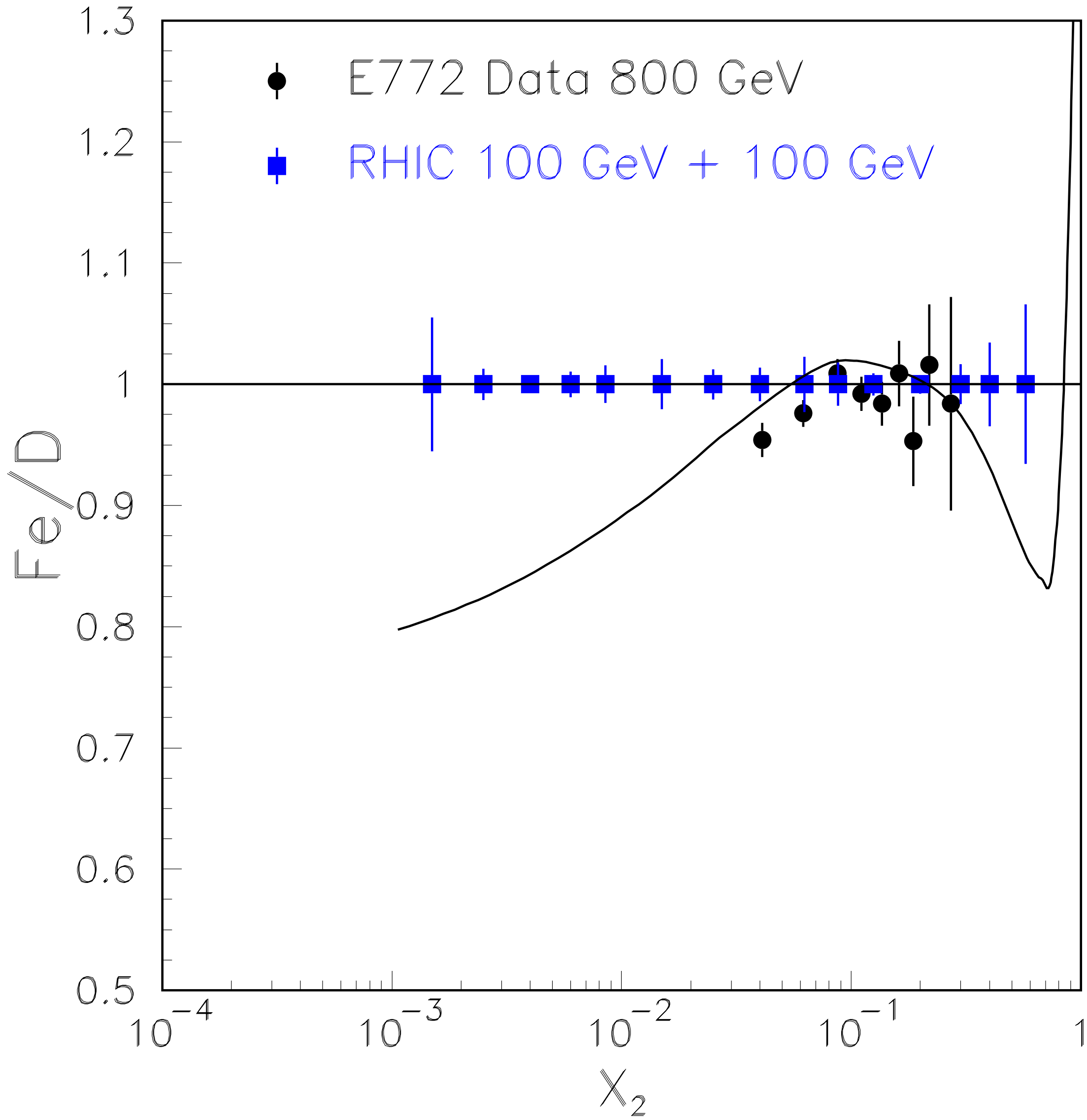

Figure 3: Projected statistical accuracy for Fe/D Drell-Yan cross section ratios as a function of X_2 in a 2-month run at PHENIX. The E772 data are also shown. The solid curve is the EKS98 parametrization for parton distributions in nuclei

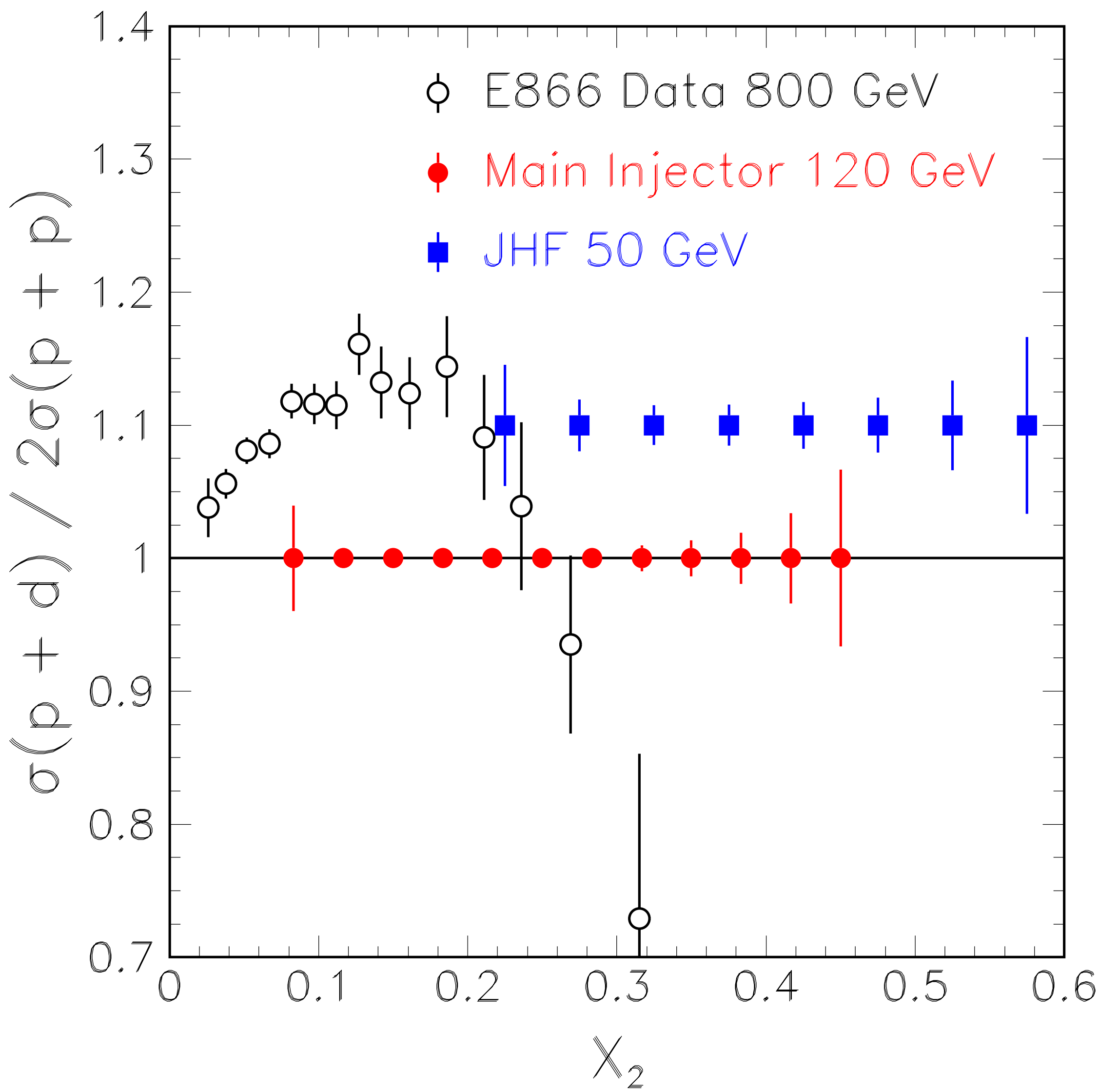

Figure 4: Projected statistical accuracy for $\sigma(p+d)/2\sigma(p+p)$ in a 100-day run at JHF. The E866 data and the projected sensitivity for a proposed measurement [26] at the 120 GeV Fermilab Main-Injector are also shown.

Three possible "p-A" running modes:

1. Symmetric running (100 GeV p + 100 GeV/μ A)

   Advantage:

   - Identical nucleon-nucleon CM energies provide a direct comparison between p-p and A-A.

   Disadvantage:

   - Collision axis will be rotated by up to $\sim$ 4 mr due to the different magnetic rigidities of proton and heavy ion beams. Detector acceptance for p-A is different from p-p and A-A.
   - DX magnets at the interactions region need to be moved.

2. Asymmetric running (250 GeV p + 100 GeV/μ A)

   Advantage:

   - Magnetic rigidities for proton and heavy ion beams are matched. Collision axis will not be rotated. DX magnets will not be moved.
   - Achieve higher CM energies. Reach wider kinematic regions (i.e. small x).

   Disadvantage:

   - Comparison between p-A and A-A is less direct.
   - Feasibility for running the proton and heavy ion beams with different speeds (different orbits in the rings) needs to be demonstrated.

3. d+A running (100 GeV/μ d + 100 GeV/μ A)

   Advantage:

   - Identical nucleon-nucleon CM energies provide a direct comparison between p-p and A-A.
   - Z/A for deuteron is much closer to heavy ions.
   - IR geometry is nearly the same as p-p and A-A.

   Disadvantage:

   - Acceleration of deuterons in RHIC requires work on the ion source and the new RFQ.

Figure 5: Pros and cons of three possible running modes for p-A at RHIC.

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